Behavioral Factors Influencing Fish Entrapment at Offshore Cooling-Water Intake Structures in Southern California

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Introduction

Fish entrapment by offshore cooling-water intake structures has generally been regarded as the result of fish attraction to these structures (Downs and Meddock, 1974; Stauffer and Edinger, 1980). However, in situ studies conducted at southern California intake structures during the middle 1970's revealed that fish entrapment was not simply a consequence of fish contacting intake water currents (Dorn et al., 1978; Dorn et al., 1979;

Helvey and Dorn, 1981; Helvey and Dorn[1]). On the contrary, intake structures were found to support diverse fish assemblages with many of these intake-associated, reef fishes swimming in and out of the intake water current without incident. Based on concomitant in-plant impingement monitoring, it was also learned that these same reef species were entrapped less frequently than nonreef species. Because earlier swimming speed studies (Dorn et al., 1979) had shown that swimming performance was not a causative factor, fish entrapment began to be viewed as a function of fish behavior.

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With this knowledge, subsequent intake studies undertaken by southern California utilities in response to Section 316(b)[2] of the 1972 Federal Water Pollution Control Act (Public Law 92-500) were designed to substantiate the interactions of both reef and nonreef fishes with intake

ABSTRACT—Seven species account for the majority of fish entrapment by offshore cooling-water intake structures in southern California. These fishes include transient species (queenfish, Seriphus politus; *white croaker,* Genyonemus lineatus; *walleye surfperch,* Hyperprosopon argenteum; *northern anchovy,* Engraulis mordax; *and Pacific pompano,* Peprilus simillimus) *which generally encounter intakes at night, and reef-associated species (shiner perch,* Cymatogaster aggregata; *and white seaperch,* Phanerodon furcatus) *which utilize intake structures as artificial reefs. The entrapment of these species results from different behavioral activities that bring these species into direct contact with the intake water currents at times when their vision is impaired or when the presence of unusual intake hydraulics disorients their position in the flow.*

For some transient species, intake encounters appear to be the result of random movements, while for many reef-associated fishes, intake encounters may be due to directional movements toward these structures. Future research focused on identifying the mechanisms that determine these movements is recommended as the most practical approach for reducing fish entrapment.

[1]Helvey, M., and P. Dorn. 1983. Entrapment susceptibility of fishes associated with an offshore intake structure: Evidence for a viable artificial reef. Occidental Coll., Los Ang., Calif. Unpubl. manuscr., 18 p.

[2]Section 316b of the Federal Water Pollution Control Act of 1972 requires that the location, design, construction, and capacity of cooling-water intake systems reflect best available technology for minimizing adverse environmental impact.
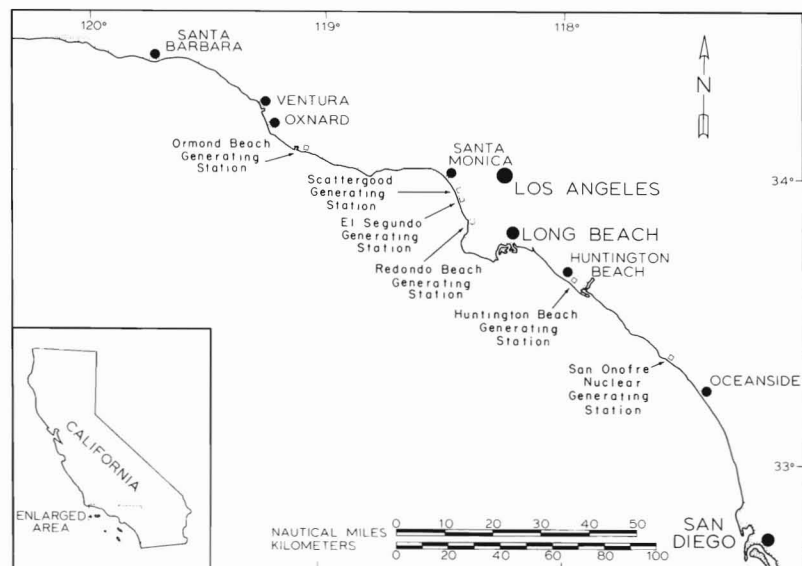

Figure 1.—Location of coastal generating stations in southern California with offshore cooling-water intake structures.

structures. These studies were divided along two lines of research: One series of studies evaluated the biological and physical factors accounting for the diverse fish assemblages residing at intakes; the other series focused on understanding the dynamics of nonreef fish encounters with intakes.

Both sets of studies generated a considerable amount of information not generally accessible that deals with the behavior of fishes interacting most often with intake structures. This paper synthesizes these findings and incorporates pertinent life history information to provide a comprehensive overview of the behavioral factors underlying fish entrapment.

Entrapment Vulnerability

Between Santa Barbara and San Diego, Calif., are six open-coastal electrical generating stations (Fig. 1). Five are operated by Southern California Edison Company (SCE) and one by the Los Angeles Department of Water and Power (LADWP). These coastal facilities use ocean water for their "once-through" cooling systems by continual withdrawal of large quantities (3.7×10^6 gpm) of seawater (Larson et al., 1979; Schuman[3]). The water is drawn through submerged velocity-capped intake structures (Weight, 1958) several hundred meters offshore (Fig. 2). During the process, juvenile and adult fishes are entrapped and subsequently impinged on facility screens.

Because intakes can be considered fish sampling devices (Hardisty and Huggins, 1975; Moazzam and Rizvi, 1980; Van der Broek, 1980), albeit biased ones (Moss et al., 1981; Stephens, 1983), accurate records of fishes unsuccessful in escaping intake water currents are kept. In a 2-year study of fish entrapment throughout the SCE system, Herbinson[4] reported 137 species entrapped by SCE open-coastal intakes. However, 95 percent

[3]Schuman, J. 1983. Los Angeles Department of Water & Power, Los Ang. Calif. Pers. commun.
[4]Herbinson, K. T. 1981. Fish impingement inventory. South. Calif. Edison Co. Res. Develop., Rosemead, Calif. Unpubl. manuscr., 157 p.
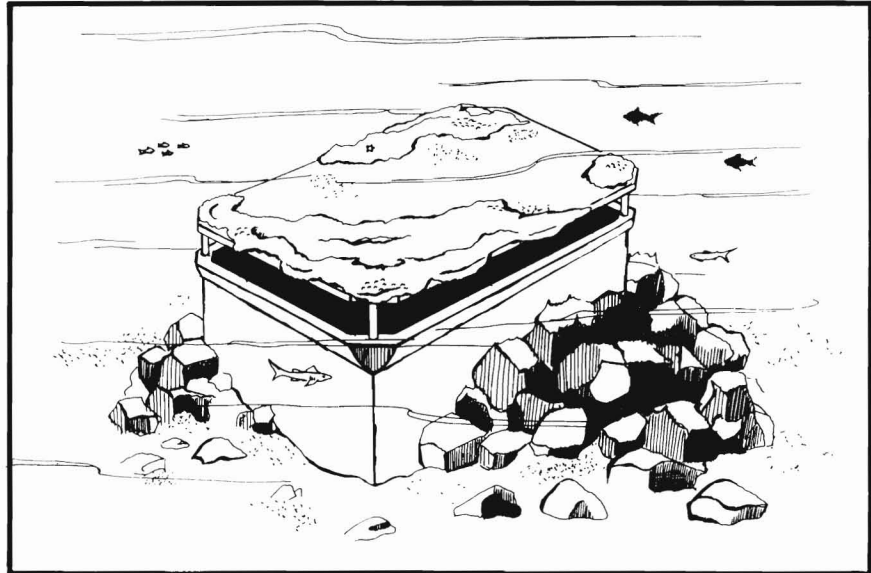
Figure 2.—A typical offshore cooling-water intake structure in southern California. Intakes consist of large vertical conduits (riser bowls) extending several meters above the sea floor and capped with a concrete slab (velocity cap). Water is withdrawn through the space between the velocity cap and riser bowl. Rock boulders strewn around the base of the structure curtail sand erosion.

Table 1.—Species most vulnerable to entrapment from October 1978 to September 1980 based on rank order of abundance for Southern California Edison Company's open coastal generating stations (adapted from Herbinson, text footnote 4).

Rank	Scientific name	Common name	No. of individuals	Percent of total	Cumulative percent
1	Seriphus politus	Queenfish	2,357,013	60.20%	60.20%
2	Genyonemus lineatus	White croaker	404,276	10.30	70.50
3	Hyperprosopon argenteum	Walleye surfperch	319,340	8.10	78.70
4	Engraulis mordax	Northern anchovy	252,363	6.50	85.10
5	Phanerodon furcatus	White seaperch	184,059	4.70	89.80
6	Peprilus simillimus	Pacific pompano	119,089	3.00	92.90
7	Cymatogaster aggregata	Shiner surfperch	69,560	1.80	94.70

of the total fish loss was attributed to only seven species representing four families (Table 1).

Two sciaenids, the queenfish, *Seriphus politus,* and the white croaker, *Genyonemus lineatus,* accounted for the majority (> 70 percent) of fish entrapped between 1978 and 1980 (footnote 4). Three embiotocids, walleye surfperch, *Hyperprosopon argenteum;* shiner perch, *Cymatogaster aggregata;* and white seaperch, *Phanerodon furcatus,* composed 14.6 percent of the total fish loss. The northern anchovy, *Engraulis mordax,* and the Pacific pompano, *Peprilus simillimus,* made up another

9.5 percent of the total mortality. These seven species, with the exception of the shiner perch and white seaperch, bear little resemblance to those species residing at intakes.

Based on data combined from several studies conducted during daylight hours (Table 2), 19 species (including white seaperch; black perch, *Embiotoca jacksoni;* pile perch, *Rhacochilus vacca;* blacksmith, *Chromis punctipinnis;* kelp bass, *Paralabrax clathratus;* barred sand bass, *P. nebulifer;* señorita, *Oxyjulis californica;* and blue rockfish, *Sebastes mystinus*) are known to commonly associate with

intake structures. Interestingly, these intake-associated species are not entrapped relative to their estimated field densities in the intake vicinity. During an intensive 12-month field and in-plant study conducted between 1976 and 1977 at the Redondo Beach facility, the eight species listed above composed 95.5 percent of the intake-field population but less than 20 percent of the total fish entrapped for that same period (footnote 1).

The presence of sizable fish assemblages at intake structures clearly demonstrates that fish entrapment is not necessarily a simple function of density nor distribution as some investigators have concluded (Murarka, 1977; Haven and Ginn, 1978; Sharma, 1978; Thomas et al., 1979b; Thomas and Johnson, 1980). We do know that entrapment in southern California waters may be a function of density for some species such as queenfish, white croaker, and northern anchovy (Fig. 3). Why, then, do such entrapment disparities exist between species? The following section examines the diel behaviors of the different species interacting with intakes which may account for these varying entrapment vulnerabilities.

Fish Behavior and Interactions With Intake Approach Velocities

A large proportion of intake fish mortalities are attributed to water-column oriented, schooling fishes that are not associated with reef structures, but whose relationship to a reef is what Turner et al. (1969) considered as incidental. The term "transient" is used here to classify these nonreef fishes (e.g., queenfish, white croaker, northern anchovy, walleye surfperch, and Pacific pompano). These species differ from "reef associated" species (Turner et al., 1969), or, more appropriately, "intake-associated" species, that have a maximal or variable relationship to the reef but at least remain associated with reefs in general for almost their entire lifetime (e.g., kelp and barred sand bass, California sheephead, *Semicossyphus pulcher*; blacksmith, señorita, black perch, white seaperch, pile perch,

Table 2.—Fish species observed in more than 70 percent of the visits to three water intake structures in southern California during three intake population studies (Helvey and James, 1979; Helvey, 1981; Helvey and Dorn, 1981).

Scientific name	Common name	Intake study
Chromis punctipinnis	Blacksmith	A, C
Coryphopterus nicholsii	Blackeye goby	A, C
Rhacochilus vacca	Pile perch	A, B, C, D
Embiotoca jacksoni	Black perch	B, D
Girella nigricans	Opaleye	D
Hypsurus caryi	Rainbow seaperch	B, D
Lythrypnus dalli	Bluebanded goby	C
Oxyjulis californica	Senorita	A, C
Oxylebius pictus	Painted greenling	A, C
Paralabrax clathratus	Kelp bass	A, B, C
P. nebulifer	Barred sand bass	A, B, C, D
Phanerodon furcatus	White seaperch	B, D
Semicossyphus pulcher	California sheephead	C
Sebastes auriculatus	Brown rockfish	B, D
S. caurinus	Copper rockfish	A
S. dallii	Calico rockfish	A, C
S. mystinus	Blue rockfish	A, B, C
S. rastrelliger	Grass rockfish	D
S. serranoides	Olive rockfish	A, B, C

[1] Key: A = Redondo Beach Units 7 & 8 Intake, 12-month study between 1976 and 1977, 33 visits; B = El Segundo Units 3 & 4 Intake, 7-month study in 1978, 10 visits; C = Redondo Beach Units 7 & 8 Intake, 7-month study in 1978, 14 visits; D = Scattergood Intake, 18-month study between 1980 and 1981, 7 visits.

shiner perch, and most rockfishes, *Sebastes* spp.).

Transient Fishes

Transient species are rarely seen at intakes during the day (Helvey and James, 1979; Helvey et al., 1980, 1981; Helvey, 1981; Helvey and Dorn, 1981). This is because most form quiescent schools during the day, inshore and away from reefs, only to become active and disperse offshore at night. For instance, Hobson and Chess (1976) observed queenfish in dense, inactive schools close to shore during the day that dispersed up to 1.5 km from these sites at night. This explains why Helvey and James (1979) only saw queenfish at intakes during the evening. Allen and DeMartini (1983) also reported white croaker and Pacific pompano to move offshore at night. Similarly, northern anchovy schools disperse at night (Mais, 1974) and offshore (Allen and DeMartini, 1983), although at particular times of the year they regroup into schooling formation (Mais, 1974; Squire, 1978). Walleye surfperch also form inshore schools during the day (Limbaugh, 1955; Feder et al., 1974)
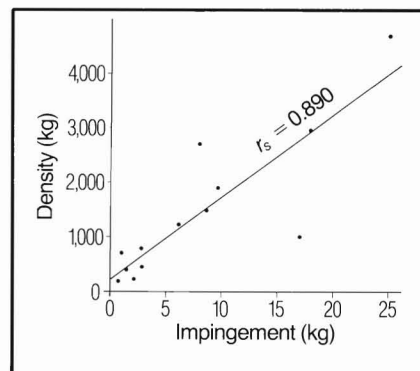

Figure 3.—Correlation between fish density (kg) in the intake area and fish impingement (kg) during hourly nighttime intervals at Huntington Beach, Calif., 1979. Results yielded a significant (P = 0.0003) Spearman rank correlation coefficient of $r_s = 0.89$ (n = 66). (From Johnson, text footnote 8.)

and disperse offshore at night (Ebeling and Bray, 1976; Hobson and Chess, 1976; Hobson et al., 1981). Using hydroacoustics, these same movements were also monitored for several species in the vicinity of the San Onofre Nuclear Generating Station on several occasions (Carlson et al., 1977; Thomas et al., 1977a, b; Thomas et al., 1979b).

These nocturnal activities appear to be primarily correlated with feeding behavior. Queenfish studies (Hobson and Chess, 1976; Hobson et al., 1981; Allen and DeMartini, 1983; Miller[5]) reveal that they feed exclusively at night on zooplankton and nekton. Walleye surfperch are also nocturnal predators (Hobson and Chess, 1976; Helvey et al., 1980; Hobson et al., 1981). Unfortunately, the feeding behavior of other transients is sketchy. Nocturnal movements and food preferences of white croaker indicate that it also feeds at night. Its prey includes polychaetes, gammarid amphipods, cumaceans, and mysids

[5]Miller, K. E. 1980. Abundances, vertical distributions, and diets of *Seriphus politus, Genyonemus lineatus,* and *Atherinopsis californiensis* (Pisces) offshore of open coastal southern California electrical generating stations. Dep. Biol., Occidental Coll., Los Ang., Calif. Unpubl. manuscr., 60 p.

(Skogsberg, 1939; Allen and DeMartini, 1983; Miller[5]; Klingbeil[6]; Ware[7]), all nocturnally emergent plankton (Hammer and Zimmerman, 1979; Hammer, 1981). Emergent zooplankton also forms part of the northern anchovy diet (Loukashkin, 1970; O'Connell, 1972), and Allen and DeMartini (1983) suggest that the nocturnal dispersion of this species is largely due to its feeding behavior.

During these evening feeding forays, many species undergo vertical shifts in the water column. Using gill nets designed for age 1+ fishes, Thomas et al. (1980b) found queenfish, white croaker, and northern anchovy distributed thoughout the water column during the evening (Fig. 4). For queenfish and white croaker, these distributions contrast substantially with their estimated daytime distributions (Fig. 5) which are normally clustered close to the bottom (Johnson[8]).

Obviously, heightened evening activities as well as associated vertical movements impose greater risks of contacting the intake water current. This may explain why fish entrapment is generally higher at night than during the day (Landry and Strawn, 1974; Grimes, 1975; Johnson et al. 1976; Thomas and Miller, 1976; Thomas et al., 1979a). In a study at the Huntington Beach Generating Station, entrapment was found to be eight times higher for all species from midnight to dawn than the remaining 18 hours from dawn to midnight (Johnson et al., 1980). Specifically, the entrapment of queenfish, white croaker, and northern anchovy was 9.5, 11.4, and 4.9 times higher, respectively, during the 6 hours between midnight and dawn.
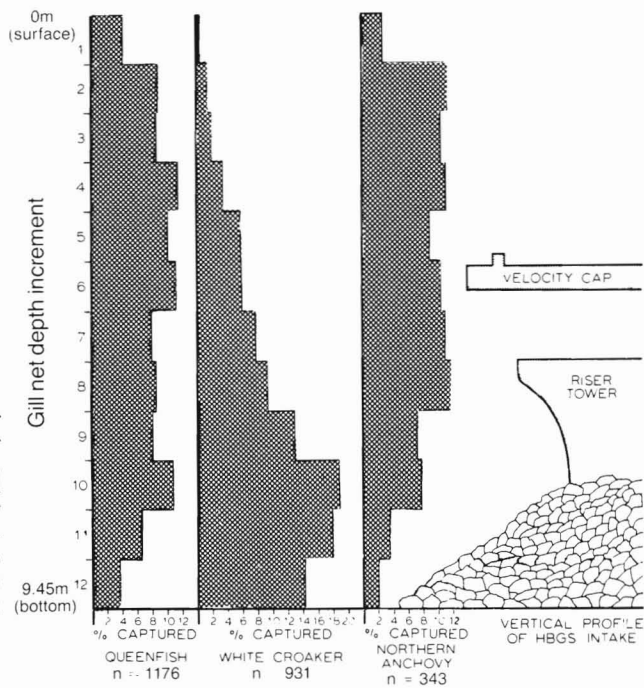

Figure 4.—Nocturnal vertical distributions of queenfish, white croaker, and northern anchovy around the Huntington Beach Generating Station (HBGS) during 36 sampling nights in 1979. (From Thomas et al., 1980b.)
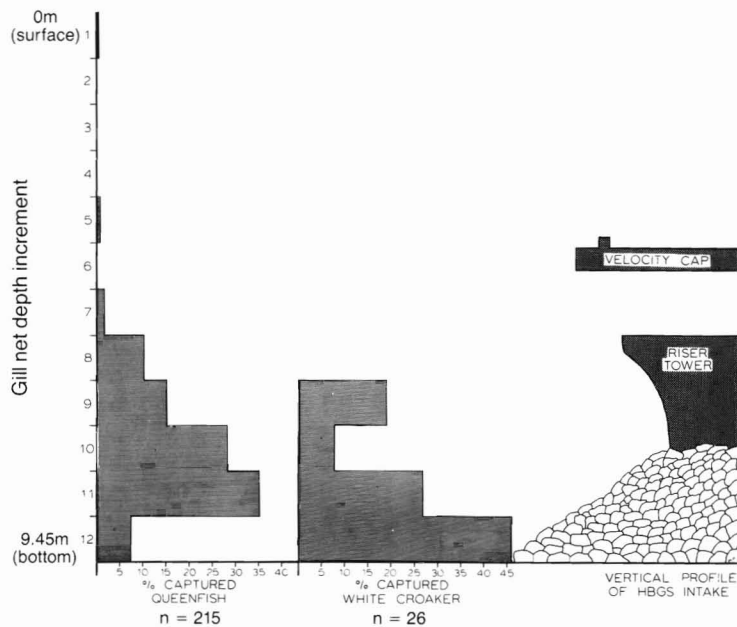

Figure 5.—Diurnal vertical distributions of queenfish and white croaker around the Huntington Beach Generating Station during 3 sampling days in 1979. (Adapted from Johnson, footnote 8).

[6]Klingbeil, R. A. 1972. Comparative study of the food and feeding habits of the teleostean fishes in Anaheim Bay, California. Masters Thesis, Dep. Biol., Calif. State Univ., Long Beach, 129 p.

[7]Ware, R. R. 1979. The food habits of the white croaker, Genyonemus lineatus and an infaunal analysis near areas of waste discharge in outer Los Angeles Harbor. Masters Thesis, Dep. Biol. Calif. State Univ., Long Beach, 164 p.

[8]Johnson, R. L. 1980. 1979 Summary report and working draft for 1980. Fish Entrapment Studies. Occidental Coll., Los Ang., Calif. Unpubl. manuscr., 181 p.

Fish are also less apt to detect intake water currents at night. During the day, fishes active in the water column are able to visually detect and maintain station in water currents by what is known as the optomotor

response (Lyon, 1904). Because this response depends upon the visual sense, it becomes impaired as light levels attenuate (Pavlov, 1969b; Arnold, 1974). Consequently, fishes cannot visually detect water currents at night and drift passively when encountering moving water (Ali, 1959; Northcote, 1962; Pavlov et al., 1968; Pavlov, 1969a; Pavlov et al., 1972). Thus, this physiological impairment, coupled with the nocturnal activities of these fishes, compounds the chances of nocturnal entrapment.

Intake-Associated Fishes

Intakes accommodate diverse fish assemblages that resemble those of other artificial reefs (Helvey and James, 1979). Intake fish communities also resemble other fish communities in the Southern California Bight in that they support unstable fish populations (Horn, 1980; Ebeling et al., 1980a; Stephens and Zerba, 1981; Stephens, 1983). Nonetheless, many species, particularly pomacentrids, embiotocids, labrids, scorpaenids, and serranids are generally present year round.

The continual presence of reef species appears related both directly and indirectly to feeding behavior. For planktivorous species such as the blacksmith and señorita (Hobson and Chess, 1976), intakes not only provide a visual reference but also provide a constant water current that these two species frequently orient to, perhaps for feeding purposes (Helvey and Dorn, 1981). Intake structures and the rock boulder substrata (riprap) surrounding them also support rich invertebrate populations which comprise a major component of the diet of intake residents (Helvey et al., 1980). For example, benthic feeding embiotocids (Limbaugh, 1955; Quast, 1968; Bray and Ebeling, 1975; Ellison et al., 1979) including black perch and white seaperch were found to feed directly on prey associated with intake riprap (Helvey et al., 1980; Helvey, 1981). Similarly, olive rockfish, *Sebastes*

serranoides; and boccacio, *S. paucispinis*; as well as kelp and barred sand bass utilize intakes as feeding locations and consume organisms associated with the riprap including emergent plankton (Helvey et al., 1980; Helvey, 1981).

With the exception of adult olive rockfish and boccacio which actively feed during the evening hours (Hobson and Chess, 1976; Helvey et al., 1980) as well as kelp and barred sand bass which periodically feed at night (Hobson et al., 1981), most intake-associated species restrict their feeding activities to the daylight hours. For species of tropical ancestry including blacksmith, señorita, and California sheephead, this means commuting to seafloor shelters at dusk where they remain all night (Wiley, 1974; Bray and Ebeling, 1975; Ebeling and Bray, 1976; Ebeling et al., 1980b; Bray, 1981; Hobson et al., 1981). This behavior removes these species from intake water currents during the critical period when these flows cannot be visually perceived. In contrast, embiotocids, possibly because of reduced predation pressures operating within temperate communities (Ebeling and Bray, 1976; Stephens and Zerba, 1981), hover in the water column at night (Bray and Ebeling, 1975; Ebeling and Bray, 1976; Helvey and James, 1979). Such behavior naturally increases their chances of contacting intake water currents, thereby increasing their entrapment vulnerability.

There is some evidence that the entrapment of intake-associated fishes may not be strictly limited to evening hours. Johnson et al. (1976) reported marked increases in the entrapment of intake-associated species during storms, which may be related to reduced water visibilities prevalent during inclement weather. Divers have also observed intake-associated species maintaining station within intake flows to be whirled around by rare intake vortices and drawn into the intake opening during the day (Dorn et al., 1978; footnote 1). The

origin of these vortices is unknown but they demonstrate that rheotropically responding fish can be occasionally overwhelmed by hydraulic phenomena.

Intake Encounters

As discussed, specific behavioral attributes associated with the activity patterns of both transient and intake-associated fishes promote their chances of encountering intake currents under suboptimal conditions. Equally important is the nature of the movements that initially bring these species to the vicinity of the intake.

Seasonality

Many species are not prone to entrapment year round because they seasonally move from intake areas. Allen and DeMartini (1983) and SCE (1981) reported that queenfish and white croaker temporarily move offshore into deeper waters during the winter months, being present at intake equivalent depths the rest of the year. These assemblages were most distinct between June and October when they formed dense nearshore populations. Johnson and Kulik[9] found similar seasonal variations for these two species in a cumulative analysis of 1971-78 otter trawl samples taken off Huntington Beach and Newport Beach, Calif. Pacific pompano undergo seasonal movements (Horn, 1970), as do northern anchovy populations which also exhibit extensive geographical movements (Messersmith, 1967). Northern anchovy movements may account for their medial occurrence in quarterly trawl surveys taken off Orange County between 1969 and 1977 (Mearns, 1977). Shiner perch also periodically form dense assemblages at intakes during the spring-fall months which corresponds to their offshore-onshore reproductive movements (Wiebe, 1968a, b).

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[9]Johnson, R. L., and B. Kulik. 1980. An analysis of the depth distribution of four common nearshore fishes in the vicinity of Huntington Beach, California. Dep. Biol., Occidental Coll., Los Ang., Calif. Unpubl. manuscr., 8 p.

Nondirectional and Directional Movements

If a species is within the general vicinity of an intake, then what factors bring it into the immediate intake area? The movements of many transient species do not appear to be specifically directed toward intake structures. Based on a series of lampara net sets used to verify the species composition of hydroacoustic targets along 3 km transects, Johnson (footnote 8) found that the cumulative densities of queenfish, white croaker, and northern anchovy in the proximal vicinity of an intake were not significantly different from their densities in the distal portions of the transect course. Comparable findings were also provided in a series of gillnet experiments using mesh sizes specifically designed for queenfish and white croaker exceeding the 1+ age class (footnote 5). Analogous to the hydroacoustic lampara studies, the results statistically confirmed that the presence of queenfish and white croaker at the intake was no different than at control sites 1.5 km upcoast and downcoast.

The evidence collected in these experiments suggests that conclusions drawn from earlier hydroacoustic studies that indicated many species were attracted to intakes during normal plant operations (Thomas et al., 1978; Thomas et al., 1979a) may have been erroneously interpreted. It is conceivable that these accounts of "fish attraction" may have been based upon sonic targets of intake-associated species that were indistinguishable from transient species.

There are, however, occasions when transient species may actually remain in the intake vicinity for periods exceeding those attributable to chance. Thomas et al. (1980a) found that increases in fish density on successive nights at an intake structure peaked when the plant recirculated its heated effluent.

These "heat treatments" are periodically conducted at night as a means of removing biofouling organisms from the cooling water

Figure 6.—Artist's rendition of the experimental tarpaulin partially covering the rock boulder (riprap) substratum surrounding the Redondo Beach Units 7 & 8 intake structure. (From Helvey et al., 1981.)

system at temperatures lethal to the fouling organisms. A consequence of these operations is that a tremendous quantity of prey organisms (e.g., gammaridean amphipods) are discharged from the intake into the water column (Helvey et al., 1980). This may elicit an "aggregative response" (Readshaw, 1973) in nocturnally active fishes as they encounter the plume of killed or paralyzed prey. Predatory fish remain for longer periods of time in areas where they successfully feed (Beukema, 1968; Hunter and Thomas, 1974). Heat treatments may, therefore, induce such species as queenfish, white croaker, and northern anchovy to remain in the intake area for extended periods, accounting for their increased field densities and concomitant entrapment levels (Thomas et al., 1980a).

While nocturnally active transients typically exhibit diel movements past intakes, intake-associated fishes, although invariably present, also exhibit movements. The occurrence of these movements was disclosed in an experiment that attempted to reduce substantially the carrying capacity of

an intake structure by eliminating its food resources (Helvey et al., 1981). To accomplish this, prey items were either removed or covered with a tough synthetic fabric (Fig. 6). An immediate effect was the disappearance of all embiotocids and serranids from the intake area. In fact, during the first month of the experiment, the intake population was basically reduced to two planktivorous species, the blacksmith and señorita (Fig. 7). However, despite this depauperate population, entrapment levels of embiotocid and serranid species remained constant. Obviously these species continued to move between the intake and adjacent reefs in the area.

Reef fish movements may be also directional, stimulated by certain environmental cues. For example, underwater sound is known to guide the directional movements of particular teleosts and elasmobranchs (Richard, 1968; Erulkar, 1972; Popper and Fay, 1973; Nelson and Johnson, 1976). The arrival of embiotocid and serranid reef fishes at artificial reefs immediately following construction (Carlisle et al., 1964;

Grant et al., 1982) suggests that some environmental cue, possibly pressure waves emanated during reef construction, facilitates fish attraction. Specific reef sounds such as crustacean stridulation noises (Nicol, 1967; Mulligan and Fisher, 1977), fish feeding (Kim, 1977; Brett, 1979) and fish swimming motions (Moulton, 1960; Konagaya, 1980), as well as specific intake noises such as flowing water inside conduits (Ross, 1976) may conceivably attract reef fishes to intake structures.

Conclusion

If indeed particular intake or reef-associated species direct their movements in response to cues associated with intakes, entrapment must be viewed as a consequence of fish "attracted" to these structures. In this context, "fish attraction" can be regarded as a taxis, that is, a response by the fish to far-field stimuli that have directional properties (Harden Jones, 1958; Fraenkel and Gunn, 1961). These stimuli are subsequently superceded by near-field stimuli serving to reinforce the length of time fish habituate the intake (e.g., reproductive, spatial, and trophic resources).

In contrast, the entrapment of transient fishes, such as queenfish, white croaker, and northern anchovy, appears to be a random process as their movements past intakes are apparently a matter of chance. While these random events cannot be extrapolated to explain the activities of other transients, it is probable that others fit this pattern.

Despite the differences that may account for the presence of the two groups at intakes, it becomes obvious that members of both groups share a common nomadic trait. In other words, the majority of fish exhibit some type of movement. Some species are constantly transitory; others only seasonally. Likewise, some species have extensive geographical ranges while others have limited homes ranges. Nevertheless, the end result of these various movements is that both transient and intake- or reef-associated fishes con-
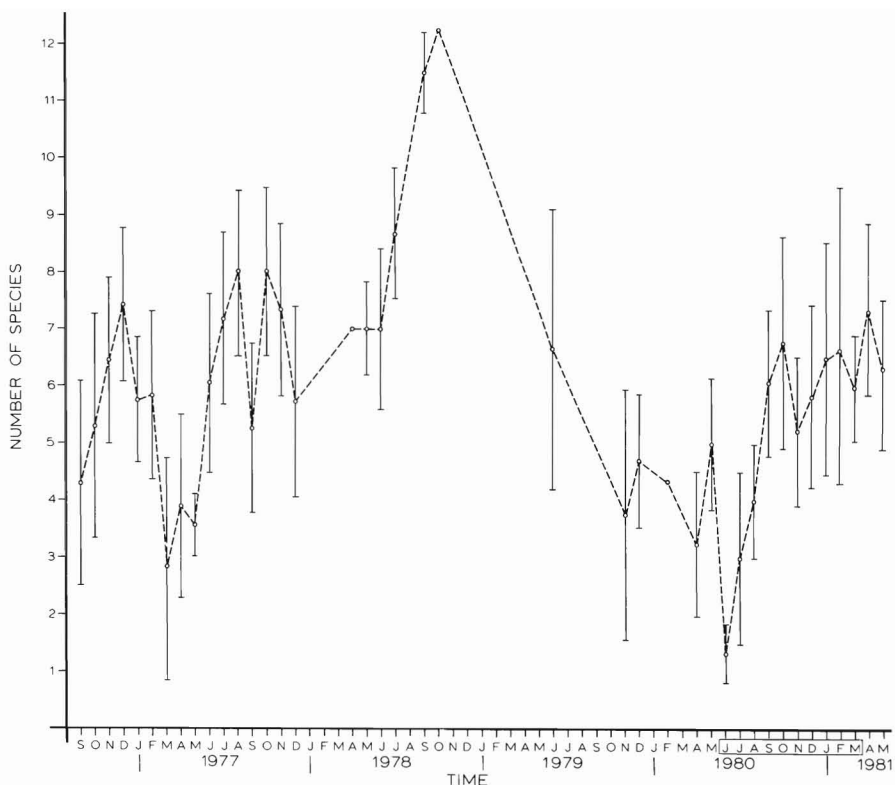

Figure 7. — Average monthly species diversity (water-column species only) at the Redondo Beach Units 7 & 8 intake structure between Sept. 1976 and May 1981. Vertical lines represent ± one standard deviation. Months enclosed within box indicate experimental period when fish did not have access to invetebrate food resources.

tinually encounter intake structures.

Therefore, because fishes will always encounter intakes, and because the physiological state of the fish (Dorn et al., 1979) as well as the quantity of water volume withdrawn (Mussalli et al., 1980) also contribute to fish entrapment, there may be a lower limit at which entrapment can be realistically reduced by means of intake design (e.g., uniform approach velocities, siting, etc.). Consequently, future research should emphasize quantifying the dynamics of fish movement past intakes. Particular attention should be given to density levels, the temporal and spatial components of these movements, and whether intakes provide directional cues. Not to be overlooked is the need to characterize unusual intake

hydraulics. Understanding the precise factors underlying fish-intake encounters will allow the problem of entrapment to be viewed from a behavioral perspective. This may be the most reasonable approach if fish entrapment is to be reduced to lowest practical levels.

Acknowledgments

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