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The Swimming Performance of Nine Species of Common California Inshore Fishes

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Abstract

The swimming performance of nine species of Southern California fish was tested in a flume at velocities of 42 to 117 cm/second. *Genyonemus lineatus* demonstrated the fastest continuous swimming ability of 61 cm/second, *Hypsurus caryi* the slowest, 42 cm/second. Five embiotocids tested demonstrated similar continuous swimming speeds ranging from 42 to 52 cm/second. Burst swimming abilities were in excess of 100 cm/second for four of five species tested; *G. lineatus* attained 137 cm/second. *Chromis punctipinnis* was the best swimmer relative to body length (BL), reaching 5.9 BL/second continuous and 11.1 BL/second burst swimming speeds. Gravid *Hypsurus caryi* had a lesser swimming ability than nongravid and male individuals of the species.

Substantial literature exists on the laboratory swimming performance of fish, including reviews by Bainbridge (1958), Blaxter (1969), and Webb (1975). However, it is difficult to use these results to predict specific capabilities of yet unstudied fish. Problems arise not only from interspecific variations, but from other factors known to influence swimming performance: size (Bainbridge 1958; Blaxter and Dickson 1959; Beamish 1966; Hunter and Zweifel 1971; Brett 1973), reproductive state (Blaxter 1969), test methods (Bainbridge 1958; Blaxter 1969), feeding (Ware 1978), time and velocity increments (Farlinger and Beamish 1977), and temperature (Rulifson 1977).

The objective of the present study was to determine the swimming abilities of several species entrapped by offshore water intakes of electric generating stations in Southern California, and to examine whether or not swimming ability can be considered a causative factor of entrapment.

Methods

Experiments were performed on fish representing the families Sciaenidae, Pomacentridae, Scorpaenidae, and Embiotocidae. Fish were captured from April through September in both 1976 and 1977 in the King Harbor area of Santa Monica Bay. Embiotocids and the pomacentrid tested were captured with box nets. Other fish were captured by hook and line. The animals were transported to the laboratory and held in covered tanks (1.5 m diameter, 0.8 m depth) supplied continuously with filtered seawater. Water temperatures ranged from 15 to 20 C. Fish were held 2–3 days prior to experimentation and were tested only once. Test individuals were fed, but not on the day of testing. The length of the individuals used was representative of the length of individuals entrapped by offshore cooling water intake structures in Southern California (Johnson et al. 1976).

Swimming performance was measured in a flume 21 m long, 1.4 m wide, and 0.7 m deep, similar to that described by Kerr (1953). A 1.8-m long section of the flume served as the test chamber. The test chamber (Fig. 1) had clear Plexiglas walls, a white painted floor, and an open top. Vertical wire barriers defined the limits of the chamber. The downstream barrier

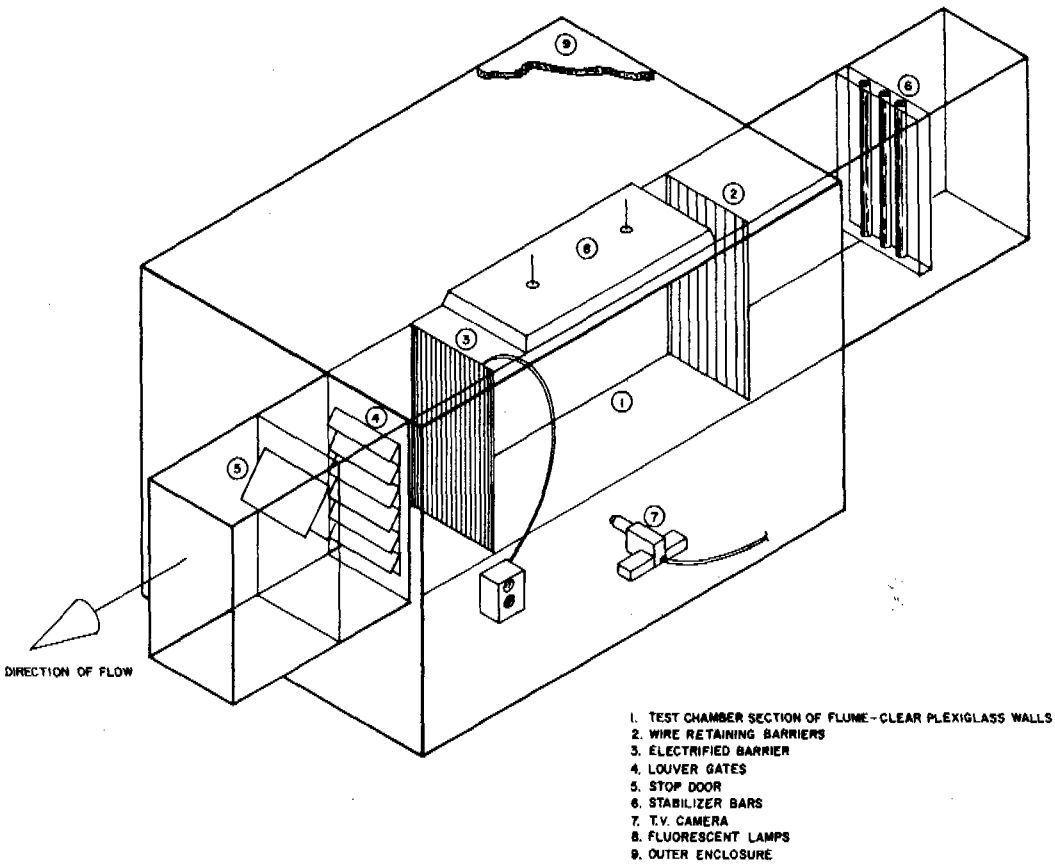

FIGURE 1.—*The swimming performance test chamber.*

was electrified with 5–10-volt alternating current to prevent fish from resting on it. Flow rates were controlled by louvers and a stopdoor at the downstream end of the flume. Stabilizer bars at the upstream end of the flume eliminated standing waves created by the upstream wire barrier and established a rectangular flow across the test chamber. The swimming performance of several species was monitored by television and recorded on videotape. Four 40-watt VitaLite fluorescent tubes supplied lighting. The test chamber was enclosed to prevent external disturbances.

Before each experiment the flow rate was adjusted, and measured with a Marsh-McBirney #511 electromagnetic current meter. After the flow was adjusted, the stopdoor was temporarily closed to reduce the flow to an acclimation rate of 15 cm/second and groups of three to five fish were placed in the test chamber. The respiration rate of test animal, indicated by counts of mouth and (or) opercular movements, reached a low steady state after 10 minutes. After 30 minutes acclimation, the stopdoor was removed; within 10 seconds the preset test flow was achieved. Test flows ranged from 42 to 117 cm/second. Swimming time until impingement on the downstream barrier was determined. Impingement occurred (fish lying flat across the wires) when the test animals were too exhausted to avoid the mild electric field that extended several centimeters from the wires. As individuals were impinged they were removed by hand or dip net to prevent other animals from using the "bow wave," created by impinged individuals, for swimming advantage (Brett 1967).

Continuous swimming abilities were defined from tests in which all animals of a species were able to swim against the experimental velocity for 60 minutes. At that time, tests were terminated; fish were not tested again. Any species

TABLE 1.—*Swimming performance of nine California inshore fishes. Continuous speeds are those maintained by the fish for more than 60 minutes. Burst speeds were measured for about 1 second after fish touched an electrified wire. Data for intermediate speeds are constants in the equation* $\log_{10}$(seconds to exhaustion) = a + b $\log_{10}$(velocity), *plus correlation coefficients for the regressions (significant at* $\alpha \leq 0.05$ *for all stated values). Continuous data were not included in intermediate speed analysis. BL, body lengths.*

Species	Standard length (cm) (mean ± SD)	Swimming performance: Continuous			Burst (mean ± SD)			Intermediate			
		N	cm per second	BL per second	*N*	cm per second	BL per second	*N*	*a*	*b*	*r*
Cymatogaster aggregata	9.3 ± 0.6	7	46	4.8	9	108 ± 0.9	10.9 ± 0.9	27	7.80	−2.97	0.76
Hypsurus caryi[a]	13.8 ± 1.2	5	42	3.1				24	6.05	−1.91	0.78
Hyperprosopon argenteum	13.7 ± 0.8	4	42	3.3				11	9.53	−3.73	0.73
Phanerodon furcatus	15.5 ± 2.2	4	48	3.1				13	10.89	−4.48	0.85
Embiotoca jacksoni	14.9 ± 2.5	5	52	3.2	3	112 ± 2.9	7.5 ± 0.4	56	8.94	−3.47	0.84
Chromis punctipinnis	8.5 ± 0.5	5	51	5.9	5	94 ± 6.5	11.1 ± 0.1	22	8.34	−3.03	0.96
Sebastes serranoides	19.8 ± 1.8	6	53	2.7				31	7.73	−2.72	0.87
Sebastes mystinus	15.1 ± 2.5	5	55	4.0	5	106 ± 11.8	7.0 ± 0.5	10			[b]
Genyonemus lineatus	19.3 ± 2.0	5	61	3.7	9	137 ± 0.1	5.9 ± 1.4	30	10.97	−4.25	0.72

[a] Nongravid.
[b] Regression was nonsignificant at $\alpha = 0.05$.

impinged upon the downstream barrier in an average of less than 100 seconds at a test velocity, was not tested at any faster flow rate. No experiments were continued past 60 minutes. The standard lengths of test animals were measured after the experiment. Embiotocids were sexed and their reproductive status assessed.

Swim speed data for female embiotocids in an advanced reproductive state were exluded from general analyses as preliminary data indicated they had reduced swimming capabilities. Swim speed tests were conducted on *Hypsurus caryi* to confirm this observation in July 1977. Tests were conducted at velocities of 75 to 77 cm/second (5–6 body lengths/second). The embryos carried by these fish were removed and weighed to develop a reproductive index, 100(embryo weight)/(total weight − embryo weight), which was compared to the swimming performance of these fish.

Swimming burst speed was determined for five species from video tape recordings of fish burst-swimming upstream after they encountered the electric field. Fish bursts of approximately 1-m distances were analyzed. Each of these observations lasted about 1 second, depending on the test fish.

Swimming data were separated into three categories: burst speeds; intermediate speeds (those between continuous and burst swimming); and continuous speeds (those maintained for the 60-minute test period). Continuous swimming performance data were analyzed separately because tests were stopped at 60 minutes and did not measure absolute performance to exhaustion. Burst speed data were not analyzed with continuous or intermediate swimming speeds. Least-squares regression values for intermediate speeds (where data of time to exhaustion at a velocity were ascertained) and statistical results were obtained by methods outlined in Snedecor and Cochran (1969) and Draper and Smith (1966).

Results

At higher velocities fish fatigued faster (Table 1; Figs. 2 and 3). The intermediate swimming spees of all fish tested except *Sebastes mys-*

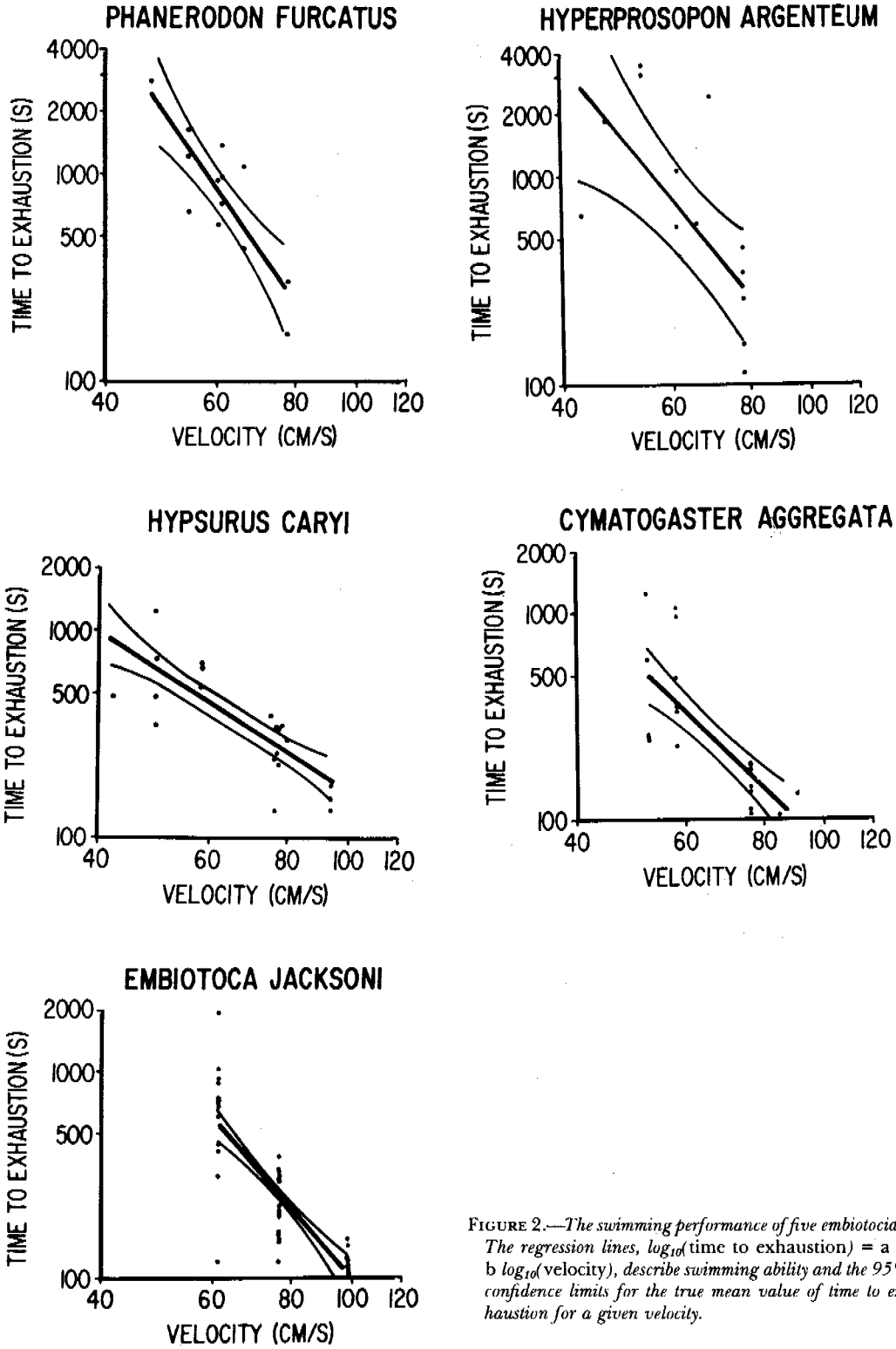

FIGURE 2.—*The swimming performance of five embiotocids. The regression lines, $\log_{10}$(time to exhaustion) = a + b $\log_{10}$(velocity), describe swimming ability and the 95% confidence limits for the true mean value of time to exhaustion for a given velocity.*

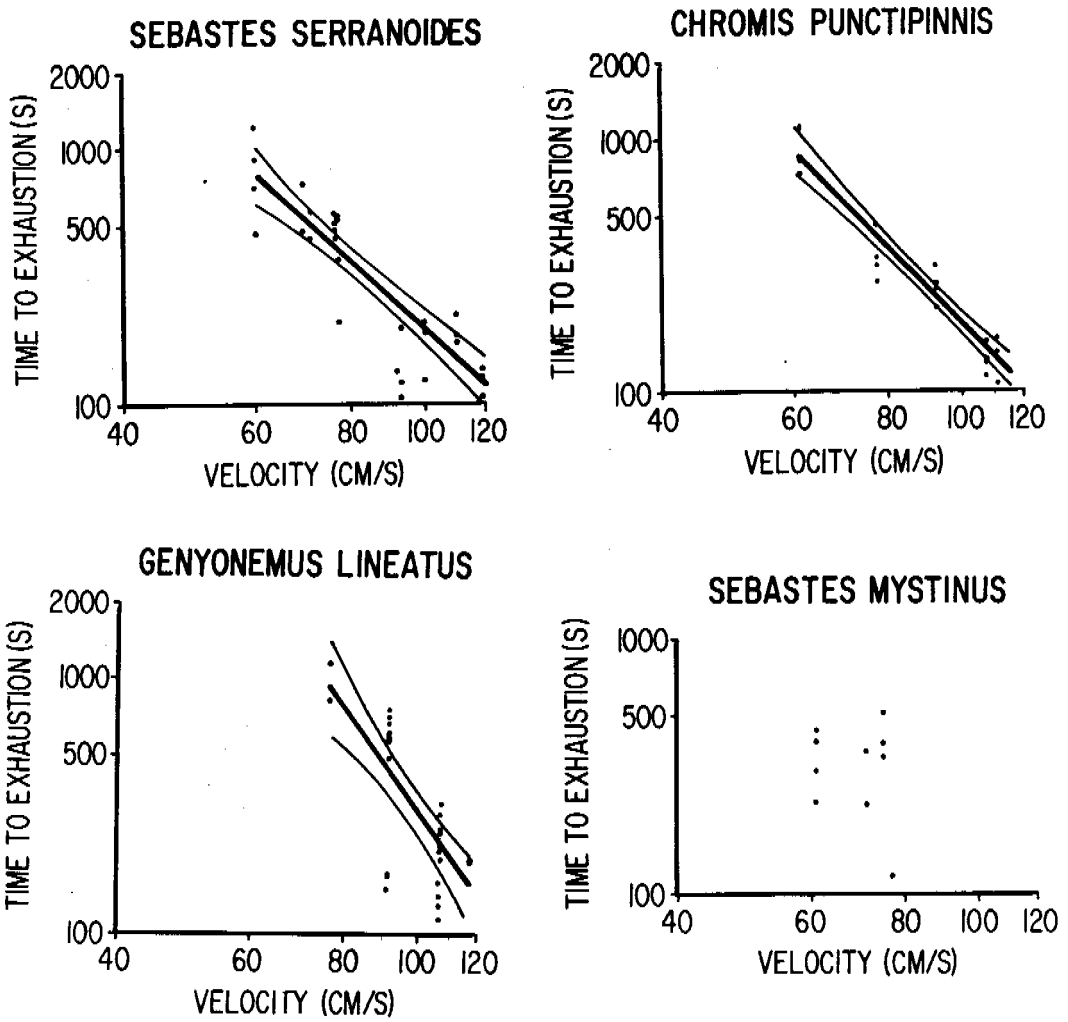

FIGURE 3.—*The swimming performance of* Sebastes mystinus, S. serranoides, Chromis punctipinnis, *and* Genyonemus lineatus. *The regression lines,* log_{10}(time to exhaustion) = a + b log_{10}(velocity), *describe swimming ability and the 95% confidence limits for the true mean value of time to exhaustion for a given velocity.* Sebastes mystinus *data did not fit a line within the 95% confidence limits.*

tinus showed consistent declining performance at higher velocities. *Hypsurus caryi* was least affected by increasing velocities as demonstrated by the low slope of the regression line. The performance of *Phanerodon furcatus* changed the most at higher test velocities, showing decreased swimming abilities.

Maximum continuous swimming speeds ranged between 42 and 61 cm/second for the nine species tested. Of the nine species, *Chromis punctipinnis* demonstrated the fastest continuous swimming speed relative to body length (BL), 5.9 BL/second.

The burst-swimming abilities were greatest for *Genyonemus lineatus,* 137 cm/second. Four of the five species tested were able to attain burst speeds in excess of 100 cm/second for at least 1 second. *Chromis punctipinnis* was the fastest species in terms of size, although it was the slowest in absolute velocity, but not significantly different from *Cymatogaster aggregata.*

As determined by a Spearman rank correlation test ($P \leq 0.05$) on 18 gravid fish, higher reproductive indices in *Hypsurus caryi* were associated with decreased swimming performance. Gravid fish fatigued faster than the 24

nongravid and male specimens tested at intermediate swimming velocities.

Discussion

Our test procedures were designed to simulate flow conditions encountered near the entrance to an offshore water intake for a power plant. Such flows are predominantly horizontal with velocities ranging between 46 and 100 cm/second. The average design flows at the entrance of offshore water intakes in Southern California are 76 cm/second (Schuler and Larson 1975). The velocity field extends up to 5 m from the intake entrance; at a distance of about 2 m from the structure, flows decrease below 30 cm/second (L. E. Larson, Southern California Edison Company, personal communication).

Test animals were acclimated at low velocities (15 cm/second), similar to ambient currents encountered offshore around power plant water intakes, and then subjected to the experimental flow rate. We felt that this technique simulated the condition that fish encountered when moving within about 2 m to the entrance of a water intake. Continuous swimming data enabled us to determine the probability with which fish would avoid impingement on protective screening in onshore screenwells if entrapped within a power plant cooling water system. Because of this rationale, we chose not to follow Brett's method of stepwise velocity increase (Brett 1964) in testing.

The swim speeds obtained in this study are comparable to those reported in Blaxter's (1969) review for many other species. The results of the present study demonstrate that even the smallest species tested are capable of escaping by burst-swimming against a water intake flow of 76 cm/second. Field observations of these fish verify this statement. Many of the species tested were observed by the authors to swim in and out of several water intakes. Only two of the nine species tested, *C. aggregata* and *G. lineatus*, are entrapped in large numbers in water intakes (Johnson et al. 1976).

The results of our experiments in conjunction with impingement data, demonstrate that the intake velocity should not be a major consideration in evaluating the causative factors of fish entrainment. Swimming performance tests would not appear to be useful for such future analytical endeavors.

Gravid *Hypsurus caryi* did not swim as well as those not in an advanced reproductive condition, implying that gravid animals are more vulnerable to entrapment.

Fish which are entrapped by offshore intakes are swept into onshore screenwells. Schuler and Larson (1975) identified a "threshold velocity" of 60 cm/second in screenwells at which fish, while positively rheotactic, were displaced downstream. Only *G. lineatus* with an average continuous swimming speed of 61 cm/second might be expected to remain upstream. Although our data show all species can burst-swim in excess of these flows, their sustained swimming capabilities are not as good. These fish will enventually tire and become impinged on downstream screens.

In summary, these data suggest that with the exception of gravid surfperch all fish tested can swim well enough to avoid power plant entrapment. It must, therefore, be a combination of additional factors such as wave surge, light level, schooling, and feeding behavior that influence the degree of impingement.

Acknowledgments

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