EFFECTS OF WATER VELOCITY ON ACTIVITY PATTERNS OF JUVENILE STRIPED BASS[1]

by

R. R. BOWLES

University of Tennessee
Ecology Program
Knoxville, Tennessee 37916
and
Environmental Sciences Division[2]
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT

The activity of 10, 25, and 50-mm juvenile striped bass exposed to water velocities ranging from static to 27 cm/sec was analyzed to determine mobility, feeding response, positional orientation, and group interaction. Increased water velocity reduced the area traveled per unit time. Presence of food also reduced the area traveled. Rheotaxis, the orientation of a swimming fish with respect to the direction of stream flow, was variable at low velocities. At water velocities of 15 and 27 cm/sec positive rheotaxis occurred frequently, while lateral and negative rheotaxis were infrequently observed. Distance between fish, a measure of group interaction, decreased with increasing water velocity and also decreased with the addition of food.

INTRODUCTION

Interactions between aquatic organisms and power plants present complex, interdisciplinary problems. Of particular interest are difficulties associated with design of cooling water intake structures and removal of organisms from the cooling water flow. The Federal Water Pollution Control Act Amendments of 1972 included in section 316(b) " . . . that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." In December 1973 the U. S. Environmental Protection Agency responded with a development document, *Minimizing Adverse Environmental Impact of Cooling Water Intake Structures* suggesting technological improvements in siting and design. However, deficiencies in understanding the causes and consequences of some intake-associated biological stresses became apparent.

Concern about loss of large numbers of valuable sport fish as well as quantities of forage organisms led to investigations of the physiology, swim speed, and behavioral response of species exposed to velocity stress associated with power plant water intake areas. Based on observations of the swim speed of young salmon and striped bass, Kerr (1953) recommended a maximum intake approach velocity of 45 cm/sec. Many intake designs, such as those developed by Bates and Vanderwalker (1970) and Schuler and Larson (1974), are based on experience in behavioral guidance gained during development of fish diversion canals and fishways. One type of intake structure, known as the velocity cap, was developed after behavioral observation showed fish were unable to resist abrupt changes in vertical currents typical of water intakes, and more easily avoided horizontal currents (Weight, 1958).

Tests of stamina and swim speed (e.g., Brett 1967 and Bainbridge 1958) provide velocity tolerance limits, but fail to consider qualitative effects of velocity on activity. Little observational data on young fish is available. Juvenile fish are highly susceptible to entrainment with cooling water taken through the power plant or impingement on cooling water intake screens. Organisms of less than approximately 50-mm length are not generally retained by intake screening and are considered entrainable. The purpose of this study is to investigate mobility, feeding response, and group interaction of entrainable striped bass *(Morone saxatilis)* exposed to velocities similar to those found in intake bays. Behavioral response under velocity stress may be an important factor in escape and survival of young bass.

METHODS AND MATERIALS

A 180 cm-diameter circular fiberglass tank was used as an observation chamber (Figure 1). Modifications included side-view portholes, a circular partition to create a 50-cm wide by 30-cm deep channel, a series of baffles to reduce turbulence, and an application of white paint to inside surfaces to provide greater visibility. Two fine mesh screens blocked the upstream and downstream ends of the 2025 cm² test area. A numbered grid drawn on the bottom of the test area was used to locate fish. Difference in water velocity between the inner and outer channel walls was slightly variable (<0.9 cm/sec at the surface). Curtains isolated the tank from external disturbance. In addition to fluorescent room light, a 150-watt flood light illuminated the test area to allow motion picture filming of fish activity. Water velocities were generated by a 1200 l/min pump and test velocities were determined by timing the travel of a float over a known distance. Striped bass fry were provided by the Tennessee Game and Fish Commission in Morristown, Tennessee and reared and tested in the laboratory.

Fish of 10 (±3mm standard deviation), 25 (±5mm s.d.), and 50 (±3mm s.d.) mm total length were tested at velocities of 0, 3, 15, and 27 cm/sec with and without food present. *Artemia* nauplii were homogeneously distributed in the test chamber when experimental groups were tested for ability to forage at the various water velocities.

Groups of 20 juvenile striped bass were placed in the test chamber at 20 (±1C) and allowed to acclimate for 30-min at 0 cm/sec. Any fish showing symptoms of stress or shock due to handling was replaced. In all cases shock and mortality due to handling were less than 10% of the test group.

Following acclimation, a series of several 3-min observations of the movements of individual fish was recorded and the entire test group was filmed for several minutes. The water velocity was increased, a 30-min acclimation period allowed, and observations again recorded. Voice recordings of numbers were taken from the background grid pattern as the observed fish moved within the test area. Activity recordings were transposed to a paper replica of the grid pattern and the area covered during an activity period calculated. For example, a 15-mm fish ranged 425 cm² per min. in a circular swimming pattern (Figure 2).

Individual frames from movies taken during observation periods for various combinations of fish size, velocity, and feeding were projected onto a piece of paper to determine distance between fish. A transect was drawn at a random distance from the projected image of the outer wall of the test chamber. At random points along the transect the distance between the premaxillaries of two fish on opposite sides of the line was measured. Three measurements were made for each of five frames taken from movies of the three sizes of fish under the four water velocities in the presence and absence of food, a total of 360 data points. Distance in centimeters was converted to body lengths and regressed on velocity.

Movies were also used to analyze the orientation of the fish with respect to water current. Positive rheotaxis (P) described a fish actively swimming against the current while negative rheotaxis (N) described downstream orientation. Lateral orientation (L) occurred when a fish positioned the long axis of its body perpendicular to stream flow. The orientation of 72 fish during 3-min activity periods tested at combinations of velocity, fish size and the presence or absence of food was observed.

Data obtained from the test groups were subjected to three treatments. Analysis of variance was used to assess the significance of fish size, water velocity, and presence/absence of food on the total area occupied by individual fish. Random pairs analysis measured the effect of water velocity and feeding activity on the distance between fish. The mean percentage of time spent in positive lateral and negative rheotaxis described the relationship of a swimming fish orienting with respect to a water current.

RESULTS

Of the variables tested water velocity had greatest significant impact on area traveled during 3-min activity observations (Table 1). Fish size and presence or absence of food had lesser, yet highly significant effects on range. Interaction between water velocity and fish size was more significant than other interactions affecting area juvenile striped bass were able to cover.

Increased water velocity significantly decreased the area ranged by 10, 25, and 50-mm juvenile striped bass in the absence of food (P<0.05) (Figure 3a). No significant difference was found in the slopes of the regression lines for the three fish sizes indicating that the magnitude of the area covered was directly proportional to the size of the fish. Area covered by 10-mm juveniles during 3-min activity periods at 27 cm/sec was nearly an order of magnitude less than area covered under static conditions.
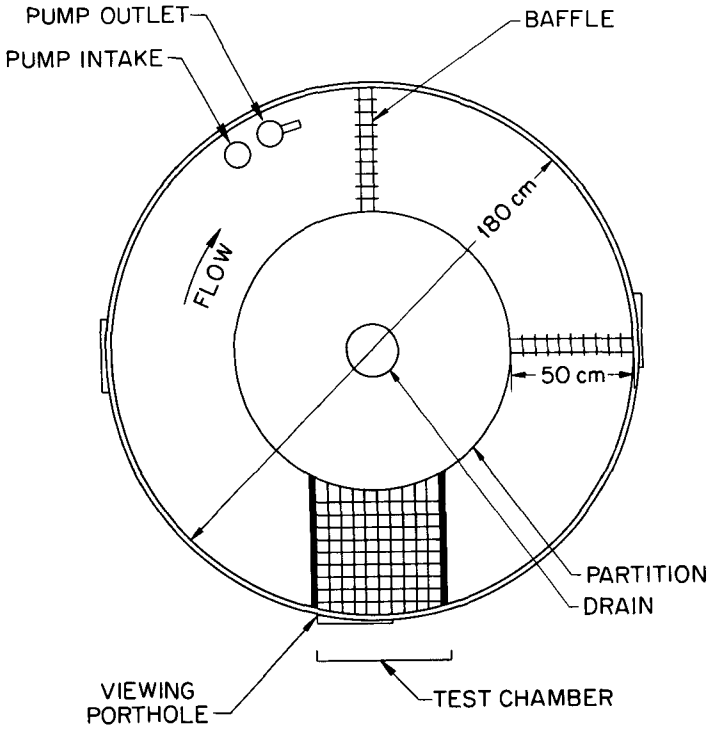
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Figure 1. Tank modifications included portholes, a circular partition, baffles, and a test chamber with a numbered grid on the bottom for monitoring fish activity.
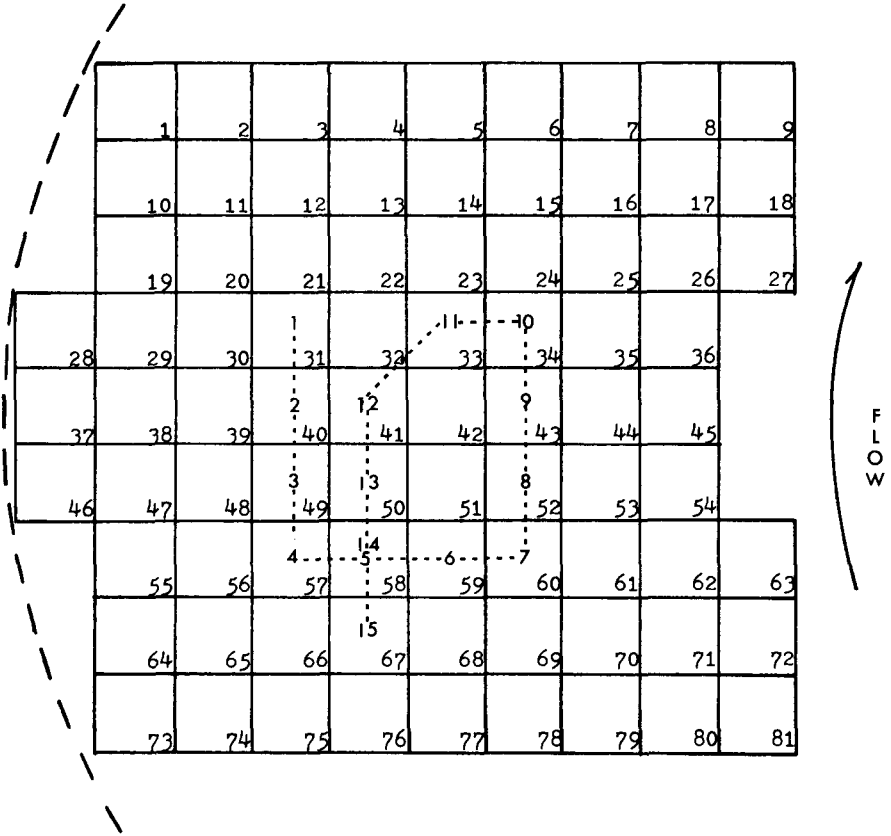
Figure 2. The 1-min activity pattern of a 25mm juvenile striped bass at a water velocity of 15 cm/sec is superimposed on a replicate of the grid pattern from the test chamber.

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Table 1. Results from analysis of variance showing the effect of fish size, water velocity, and presence/absence of food on the area traveled by juvenile striped bass during a 3-min observation period

Source of variation	df	SS	MS	F
Water velocity	3	112,563.9	37,521.3	8,128.2[1]
Fish size	2	35,902.6	17,951.3	3,888.8[1]
Food present/absent	1	956.0	956.0	207.1[1]
Water velocity × Fish size	6	4,580.5	763.4	165.4[1]
Water velocity × Food	3	249.2	83.1	17.9[1]
Fish size × Food	2	384.2	192.1	41.6[1]
Velocity × Size × Food	6	70.2	11.7	2.5[2]
Error	216	997.1	4.6	—

[1] Significant at P < 0.001.
[2] Not significant at P < 0.05.

● 10-mm STRIPED BASS
△ 25-mm STRIPED BASS
○ 50-mm STRIPED BASS

(a) EFFECT OF VELOCITY ON RANGE
WITH NO FOOD PRESENT

(b) EFFECT OF VELOCITY ON RANGE
WITH FOOD PRESENT

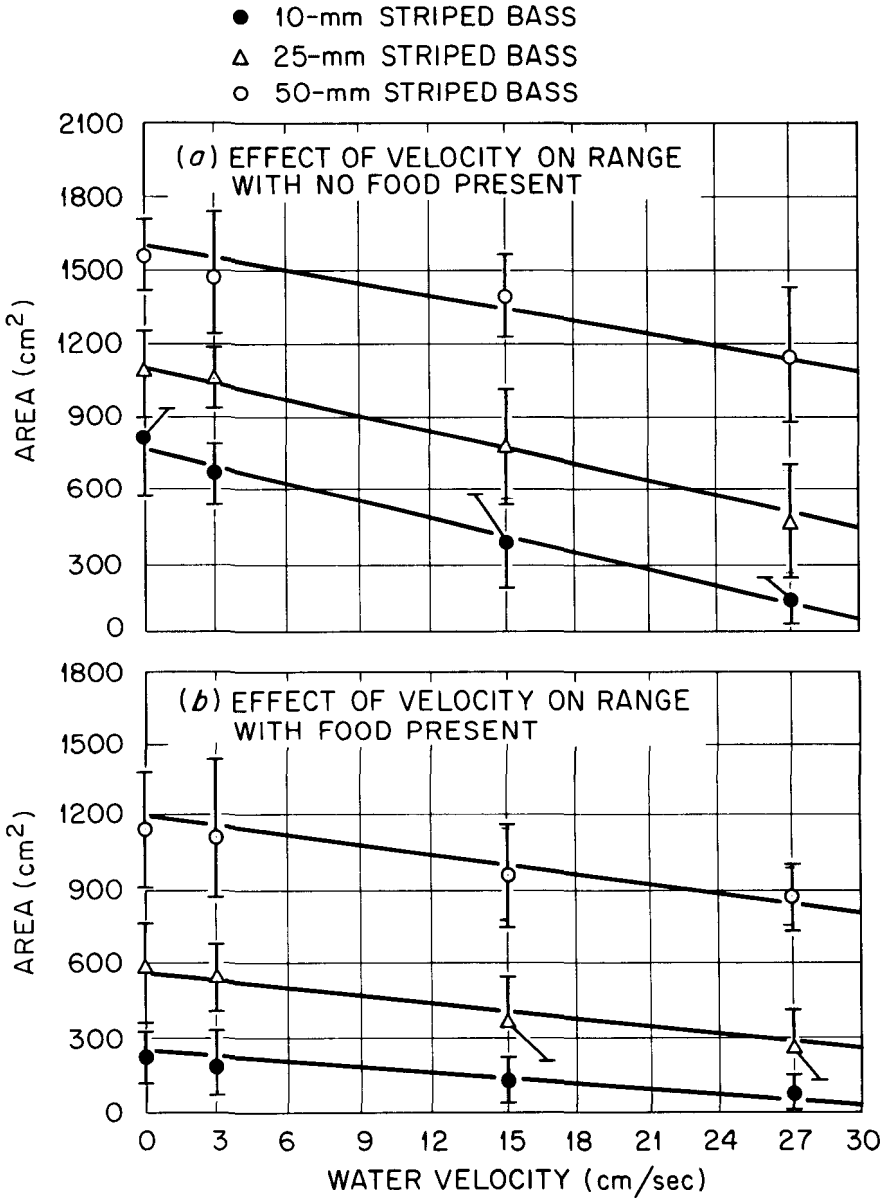AREA (cm^2)

WATER VELOCITY (cm/sec)

Figure 3. The effect of increasing velocity on juvenile striped bass mobility in the presence and absence of food. Each data point represents mean area occupied by 10 fish during a 3-min observation period. Bars show one standard deviation.
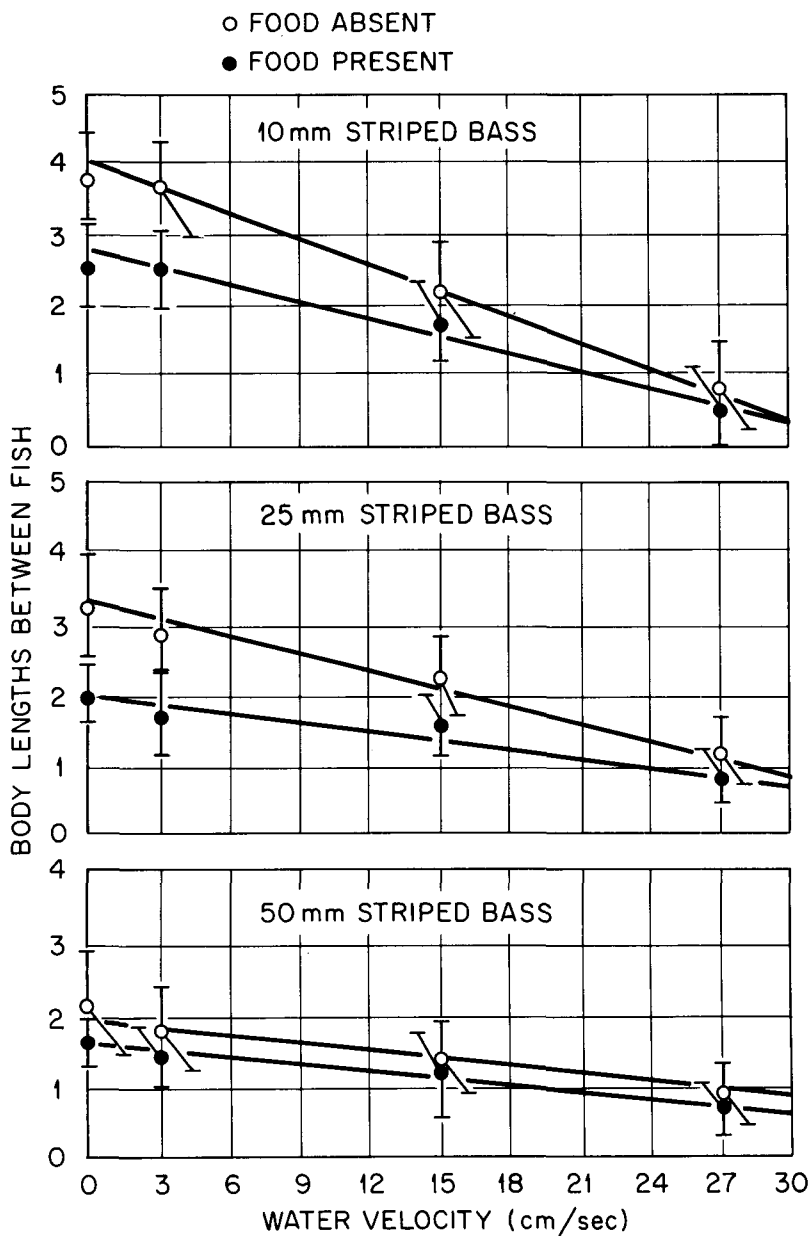
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Figure 4. The relationship of water velocity and distance between fish for 3 sizes of juvenile striped bass. Each point represents the mean from 15 samples. Bars show one standard deviation.
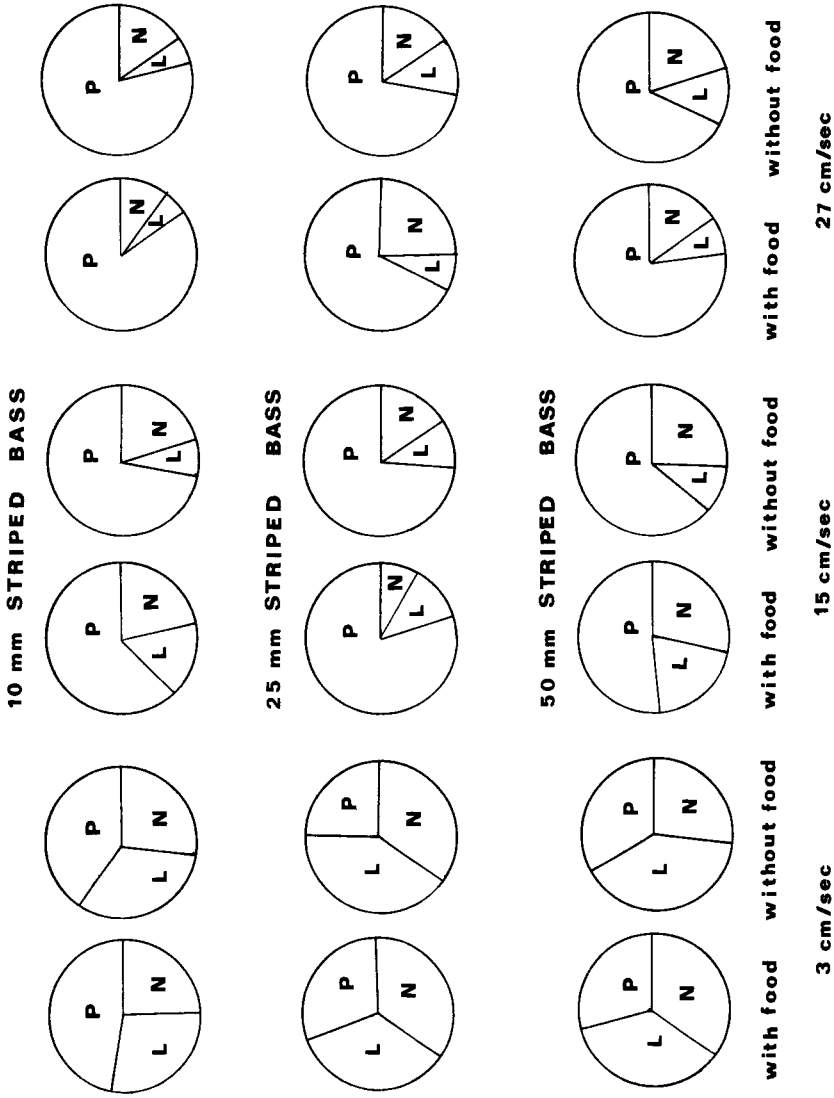
Figure 5. Mean percentage of the 3-min observation periods spent in positive (P), negative (N), or lateral (L) rheotaxis at the various test velocities. Each section represents the mean of 3 observation periods.

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Presence of brine shrimp (Figure 3b) significantly reduced the area ranged by all juvenile fish tested (P<0.01). The small size of the food organisms may have biased the data. Fish 10 and 25-mm in length reacted quickly and visibly to the presence of food while the reaction of 50-mm fish was subdued and nearly imperceptible. Area foraged by juvenile fish was proportional to fish size. For all juveniles tested the effects of increased water velocity were more marked in the absence of food.

Distance between fish decreased as water velocity increased (Figure 4). The presence of food significantly (P<0.05) reduced distance between 10 and 25-mm striped bass. Spacing between 50-mm juveniles was not significantly reduced by the presence of food. The 10-mm fish under static conditions maintained the greatest inter-fish distance in body lengths between fish. Actual body contact was observed infrequently among 10-mm bass at 27-cm/sec and no contact was observed for larger fish. A minimum spacing equal to at least 0.5 body lengths was maintained by the majority of test fish.

Positive rheotaxis was the dominant orientation accounting for 25 to 81% of all observations (Figure 5). At a water velocity of 3 cm/sec young striped bass spent nearly equal amounts of time in positive, lateral and negative rheotaxis. Lateral rheotaxis decreased as velocity increased ranging from 40% at 3 cm/sec to 3% at 27 cm/sec. Negative rheotaxis was variable, but generally decreased as velocity increased ranging from 39% to 8% of a 3-min activity period. Presence of food had little impact on rheotactic response.

When no food was present young striped bass often remained in the lower third of the 30-cm deep water column. Occasionally 25 and 50-mm fish rose to the upper third of the water column under low flow conditions. At 27 cm/sec all fish observed remained very close to the bottom of the test chamber. Little attraction to the sides of the test chamber was observed.

When food was present vertical movement occurred throughout the water column at all water velocities tested except 27 cm/sec. A weakly stereotyped feeding sequence was observed. Once visual contact with prey was made, young bass darted upstream quickly, engulfed the organism, and sank down within the water column about two body depths. Fish then returned to approximately the area where prey had first been sighted. Several feeding sequences were rapidly repeated in the same location. Awareness of the downstream screen apparently decreased during feeding; several apparently unstressed fish made caudal fin contact with the screen at velocities of 15 and 27 cm/sec.

All 25-mm juvenile striped bass displayed a swimming posture different from other size fish. While 10 and 50-mm bass swam with the long axis of the body parallel to the bottom of the tank during all activity except vertical movement, over 100 measurements made on isolated frames of movie film showed 25-mm fish swam constantly at a heads-up angle of 20° (±3° s.d.) with respect to the bottom of the tank.

DISCUSSION

As water velocity increased juvenile striped bass spent greater portions of the 3-min observation period maintaining station. At 27 cm/sec fish 10-mm in length rarely made progress upstream. Juveniles of 25 and 50-mm more frequently made upstream progress, but were subsequently washed back. No net gain in area covered occurred during such a swimming pattern. All sizes of fish tested at 27 cm/sec would be highly susceptible to entrainment because they lack substantial ability to escape from the water intake canal. At the highest test velocity fish of all sizes sought the slower moving fluid boundary layer adjacent to the bottom of the test chamber.

When food was present, area covered by juvenile striped bass decreased. Visual cueing seemed to play an important part in feeding. Feeding sequences observed suggested foraging was repeated in the same location until no food was available. During feeding the juveniles reduced inter-fish distances. Both the repetitive feeding sequence and the decrease in distance between fish may have resulted in less area covered with food present than without food present.

Observations indicated juvenile bass may be more susceptible to entrainment/impingement during feeding. Perception of the downstream screen decreased to the point of repeated tail contact in several groups tested with food present. Impingement of a 10-mm fish was observed at 15 cm/sec with food present. Location of cooling water intake structures in areas rich in forage species may result in greater loss of juvenile fish not only because larger numbers of fish frequent the area, but also because perception of the intake is reduced during feeding.

Adult striped bass are a schooling species. Shaw (1970) defined schooling as the result of biosocial attraction among fish. However, juvenile striped bass observed exhibited only weakly polarized schooling behavior. In truely polarized schools all fish orient the same direction and move as a unit.

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Schooling may play a significant part in entrainment/impingement. Many of the more susceptible and valuable fish impinged on intake screens are schooling species.

Side-to-side spacing was shown by Cahn (1972) to be important in communication among a schooling species of tuna, *Euthynus affinis*. Thus, inter-fish distance was examined as a means of expressing the effect of velocity on group interactions. As velocity increased inter-fish distance decreased. Under all flow conditions except static, a majority of the fish within each test group occupied the same horizontal plane. Breder (1965) observed similar behavior in schooling fish swimming at moderate cruise speeds and suggested vorticies created by movement of water over the mass of near-by fish may have increased locomotor efficiency. Areas of microturbulence generated by vorticies shed from the caudal fins of leading fish may influence spacing.

Keenleyside and Hoar (1954) state that failure of positive rheotaxis in fish exposed to current may reflect fatigue. A 30-min test period was not sufficient to cause fatigue, but positive rheotaxis increased as velocity increased. Rheotaxis may provide a behavioral end-point for velocity stress useful in laboratory and field conditions where flow patterns are known.

The swimming position of 25-mm juvenile striped bass may be explained by differential growth of the caudal region that temporarily caused the swim bladder to occupy a more forward position at this growth stage. The position seemed to have little effect on mobility or feeding.

In designing cooling water intakes and fish retrieval/by-pass systems detailed information on activity patterns of juvenile fish is needed. Behavioral observations under simulated intake conditions showed increased water velocity had significant effect on positional orientation, area ranged, and spacing between juvenile striped bass. By combining swim speed tolerance with qualitative observations of swimming behavior under a variety of experimental conditions, a less lethal intake technology could be developed.

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