VERTICAL DISTRIBUTION OF CAGED ESTUARINE FISH IN THERMAL EFFLUENT SUBJECT TO GAS SUPERSATURATION

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Abstract: Depth distribution of tarpon (*Megalops atlantica*), pinfish (*Lagodon rhomboides*), Atlantic Croaker (*Micropogon undulatus*), black drum (*Pogonias cromis*), and striped mullet (*Mugil cephalus*) placed in cylindrical cages extending from the surface to the bottom of the thermal effluent of a steam-electric power plant was monitored daily using a depth locator. Temperature, conductivity, pH, dissolved oxygen, turbidity, and gas saturation levels were recorded immediately after recording the depth distribution data. Overall trends suggested that intraspecific interaction had an effect on fish distribution. Pinfish, black drum, and Atlantic croaker reacted to ambient light levels. Mean depth of pinfish, black drum, and striped mullet was shown to be significantly correlated with %-total gas saturation. Tarpon and black drum responded to temperature, croaker responded to conductivity, and striped mullet responded to %-oxygen saturation.

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As the increasing world population demands greater quantities of electricity, an accompanying increase in the demand for waters required by steam-electric power plants for cooling purposes is to be expected (Cairns 1972; Federal Energy Administration 1974). Among the potential benefits that can be derived from this situation is the use of the thermal effluent of power plants for the extension of aquaculture growing seasons into the colder months of the year (Strawn 1969; Kaehler 1975; Chamberlain and Strawn 1977). However, the use of thermal effluents for culture purposes can be fully realized only after the effects of these effluents on culture organisms are determined.

A major problem in the use of heated effluent for aquaculture is that air-saturated water, when heated rapidly through the condenser tubes of a power plant becomes gas supersaturated owing to thermal reduction in solubility of atmospheric gases. Organisms exposed to this water often develop gas-bubble disease (Demont and Miller 1971; Marcello and Strawn 1973; Chamberlain and Strawn 1977). In searching for a means to prevent and cure gas-bubble disease (GBD), Gorham (1899) discovered that compensation to supersaturated conditions could be achieved by the increase in hydrostatic pressure brought about by an increase in water depth. Studies have shown that fish restricted to depths below 1 m survive periods of gas supersaturation longer than fish held at surface levels (Weitkamp 1976; Chamberlain and Strawn 1977). Percentage survival among salmonids has been shown to increase during periods of gas supersaturation when they were allowed to sound to depth, but they did not always sound deeply enough to fully compensate for high levels of gas saturation (Ebel 1969; Dawley et al. 1976; Weitkamp 1976).

Any entity which provides a signal permitting an organism to respond behaviorally can be classified as a directive factor (Fry 1971). Tesch (1975) gave the following description of the directive factors associated with migration: "Most short distance horizontal migrations of fish are initiated by search for food, more suitable hydrographic

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conditions (e.g. temperature, salinity, water movement), shelter or spawning places." When certain species are placed in groups within artificial boundaries, social behavior can act as a directive factor by altering the distribution of individuals within the confines (Gibbard 1979). Both Fry (1971) and Tesch (1975) provide a review of experiments monitoring the response of fish to directive factors.

The objectives of this study were: 1) to observe both the long term and diel depth distribution of several species of finfish in cylindrical cages extending from the surface to the bottom of the discharge canal of a steam-electric power plant; and 2) to investigate the effects of gas saturation levels, temperature, conductivity, pH, turbidity, and intraspecific behavioral interactions on the depth distribution of the fish. To meet these objectives, tarpon, pinfish, Atlantic croaker, black drum, and striped mullet were stocked in cages placed in the discharge canal of a steam-electric power plant. Depth distribution of these fish was usually recorded at daily intervals. Hydrological parameters were measured immediately after recording the distribution data, and conclusions were drawn regarding the effects of water quality changes on the distribution of the fish.

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MATERIALS AND METHODS

Description of the Area

This research was performed at the discharge canal of Houston Lighting and Power Company's Cedar Bayou Generating Station located in Chambers County near Baytown, Texas. The plant draws cooling water of brackish quality from adjacent Cedar Bayou, and discharges it into a 1053-ha cooling pond via a 9.8-km canal. The designed maximum width and depth of the canal are 58.5 m and 4.0 m, respectively.

Experimental Period

Due to prohibitively high summer temperatures in the discharge canal, this study was divided into 2 phases. The first phase was conducted from 10 March 1977 to 4 May 1977 (56 days). Species tested were pinfish and black drum. The second phase began on 2 November 1977 and ended on 29 January 1978 (93 days). Species tested in this interval were tarpon, pinfish, Atlantic croaker, black drum, and striped mullet.

Equipment

Cylindrical cages measuring 3.96 m in depth and 0.6 m in diameter were constructed from plastic coated wire with a mesh size of 1.3 by 2.5 cm. Concrete weights (20 kg total weight) were placed inside the cages for anchoring against the current. Plywood lids were secured to the top of each cage using elastic cord. Holes were drilled through the middle of each lid to facilitate insertion of the transducers. The cages were secured with nylon rope to a wooden platform placed approximately 0.5 m from the origin and in the middle of the discharge canal.

Depth distribution of the fish was recorded using a depth locator modified to detect fishes as small as 150 mm total length, spaced at least 150 mm apart, and located a minimum of 150 mm from either the surface or the bottom of the water column. Transducers were equipped with 30-m extension cables to permit depth readings to be taken from shore in order to minimize bias resulting from the presence of the investigator.

Sections of PVC pipe measuring 0.7 m long and 3.8 cm inside diameter were used to house the transducers. The end of the pipe placed in the water was capped with a piece of 1-cm thick plexiglass glued in place with silicone aquarium sealant. The pipe was placed through the hole in the cage lid, and was secured using a hose clamp that was attached to the lid with wire. The top of this assembly was covered with plexiglass to keep out excess moisture. A small amount of soap and water was kept inside the pipe to prevent air-bubble formation between the transducer and the plexiglass plate that could cause a false reading.

Stocking Procedure

Prior to placement in cages, all fish tested, except tarpon, were held for at least 2 weeks in a 0.1-ha pond. After stocking in cages, a period of at least 10 days was allowed to pass before depth distributions were monitored. One cage each was stocked at 20 fish per cage for all species, except, from March 1977 to May 1977, when 2 cages of black drum were stocked for monitoring at 20 fish per cage.

Data Collection

Throughout both phases of the study, fish distribution was usually recorded daily between 1200-1500 hours. Hydrological data were always taken immediately after recording the distribution data. On 3 occasions during March 1977 - May 1977, diel depth distribution readings were taken and hydrological data monitored at 3-h intervals.

Analytical Procedures

Mean depth for each depth-distribution recording was calculated according to the following formula:

$$\text{MEAN DEPTH} = \frac{(F1 \times 0.33 + F2 \times 0.66 + \ldots + F11 \times 3.63 + F12 \times 3.96)}{n}$$

where F1 - F12 = the number of fish observed at each of 12 discrete 0.33-m levels of depth; n = the total number of fish in the cage at the time the distribution was recorded.

Because preliminary investigations indicated that distributions were either bimodal, or in the case of pinfish trimodal, data for such modal groups were treated separately whenever modes appeared. A subroutine was employed to divide the data whenever a zero value at one of the depth intervals within the distribution of the fish was encountered. Mean depth for each modal group was then calculated using the same formula, except that n was adjusted to represent the number of fish within each group. Characteristically, one modal group was much larger than the other(s). If no zero value was encountered at any of the depth intervals within the distribution of the fish, it was concluded that their distribution was unimodal. Whenever more than 2 modal groups were discovered by this method, the smallest modal groups were combined and treated as one.

The values for mean depth (all fish, large modal group, small modal group) were separately regressed on the hydrogical data using a stepwise regression technique. Formulae for the calculation of %-total gas, %-nitrogen and %-oxygen saturations are described by Romanowsky (1979). The following functions were included in the list of independent variables to determine if distributions cycled with respect to time.

$$\text{COS (TIME)} = \left[\text{Cosine} \left(\frac{6.28}{24}\right) \times \text{Time}\right]$$

$$\text{SIN (TIME)} = \left[\text{Sine} \left(\frac{6.28}{24}\right) \times \text{Time}\right]$$

where Time is the hour (24-h clock) of the day when the readings were taken. These functions reflect changes in light intensity more accurately than hour of day in a regression analysis. Models were formed from the regression output to attempt to explain both the day-to-day and the 24-h variation in the depth distribution of the fish. Significance was set at the 0.05 level.

RESULTS

Hydrological

Minimum and maximum hydrological values from the discharge canal taken in conjunction with depth-distribution recordings are presented in Table 1. Refer to Romanowsky (1979) for plots of hydrological parameters. With the exception of turbidity, %-nitrogen saturation, and %-oxygen saturation, between-day fluctuation in the hydrological parameters was generally small. A diel fluctuation pattern was observed in temperature, dissolved oxygen, %-total gas saturation, and %-oxygen saturation. Highest values of these parameters were recorded in the late afternoon, and lowest values were recorded in the early morning.

TABLE 1. Minimum and maximum values for hydrological parameters recorded in the discharge canal.

	Mimimum	Maximum
Temperature (°C)	14.5	35.5
Conductivity-Salinity (mmhos/cm-ppt)	2.3-0.8	38.0-23.8
Dissolved oxygen (ppm)	5.4	12.0
pH	6.9	9.1
Turbidity (FTU)	9.0	97.0
%-Total gas saturation	105.9	126.7
%-Nitrogen saturation	104.4	128.6
%-Oxygen saturation	69.2	141.6

The following interrelationships were discovered among the hydrological parameters (Fig. 1): 1) temperature was observed to be inversely related with conductivity; 2) a negative correlation was observed between temperature and %-total gas saturation; and 3) conductivity and turbidity were observed to be inversely related.

Fish Distribution

Tarpon - Significant correlation between the daily variation in the depth distribution of tarpon and the hydrological parameters (Table 2) was obtained only for the small modal group and only to temperature. This relationship was non-linear (Fig. 2).

Pinfish - Daily variation in the mean depth using all the pinfish was significantly correlated only with conductivity. Mean depth of the large modal group was significantly correlated with conductivity and %-total gas saturation, while mean depth of the small modal group was significantly correlated with turbidity. Statistically, the greatest amount of daily variation in the depth distribution of pinfish was explained by analyzing the small modal group (Table 2). A quadratic function best described the variation in the large modal group of pinfish with respect to conductivity, while the response of the same group to %-total gas saturation was linear. The relationship between the small modal group and turbidity was non-linear (Fig. 3).

Diel variation in the mean depth using all the pinfish was significantly correlated with dissolved oxygen and time of day. Mean depth of the large modal group was significantly correlated with pH and %-oxygen saturation, while variation in the small modal group was significantly correlated only with time of day. The highest correlation was obtained by analyzing the large modal group (Table 1). The response of the large modal group to pH was linear, while the response of the same group to %-total gas saturation was not. The small modal group displayed a sigmoid relationship with time of day (Fig. 4).

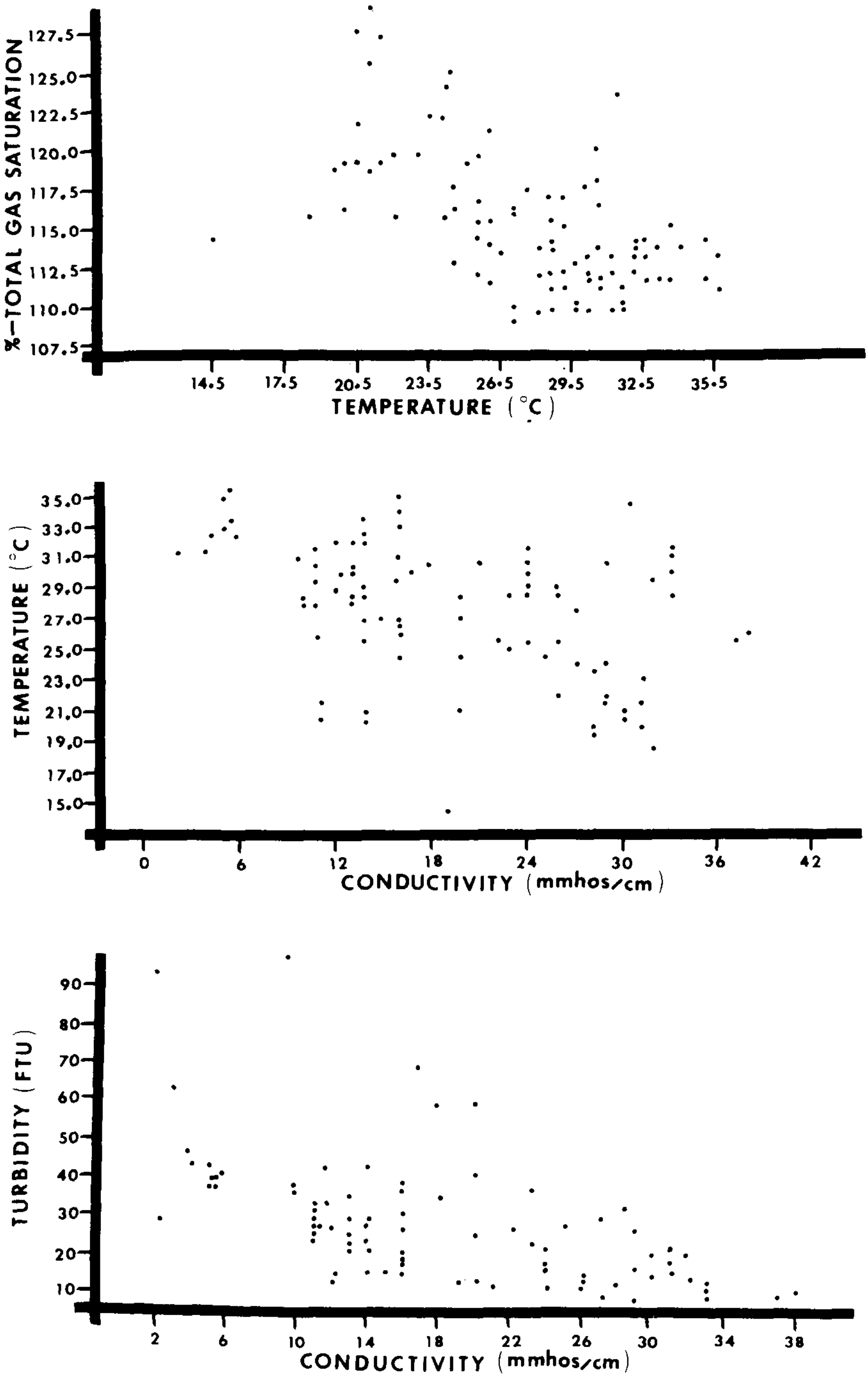

Fig. 1. Interrelationships observed between hydrological parameters taken in the discharge canal.

TABLE 2. Significant results (0.05 level) of regression analysis on the fish distribution data.

SPECIES	PERIOD & TYPE		EQUATION	r^2
Tarpon	II Daily	A	N.S.	-
		L	N.S.	-
		S	$y = 3.44 - 0.0004TSQ$	0.276
Pinfish	I + II Daily	A	$y = 1.362 + 0.007CON$	0.100
		L	$y = -0.843 + 0.0001CONSQ + 0.018TG$	0.177
		S	$y = 3.169 - 0.00009TURSQ$	0.228
	I Diel	A	$y = -0.581 + 0.22DO - 0.13CHR$	0.592
		L	$y = -1.42 - 0.18pH + 0.0003TGSQ$	0.595
		S	$y = 2.91 - 0.21CHR$	0.217
Croaker	II Daily	A	$y = 2.09 - 0.014CON - 0.0001TURSQ$	0.193
		L	$y = 2.91 - 0.09CON + 0.002CONSQ - 0.0001TURSQ$	0.291
		S	$y = 9.29 - 0.45T + 0.008TSQ + 0.41CHR$	0.269
Black drum	I + II Daily	A	$y = -1.58 + 0.0003TSQ + 0.0002CONSQ + 0.024TG$	0.201
		L	$y = -3.24 + 0.0005TSQ + 0.0003CONSQ + 0.036TG$	0.261
		S	$y = 5.139 - 0.018N_2 - 0.00004TURSQ$	0.134
	I Diel	A	$y = 1.29 - 0.0133CHR$	0.152
		L	$y = 1.006 - 0.122SHR - 0.149CHR$	0.245
		S	$y = 2.78 - 0.24SHR$	0.191
Striped mullet	II Daily	A	$y = 0.78 + 0.007O_2$	0.217
		L	$y = -0.71 + 0.00009TGSQ + 0.008O_2$	0.412
		S	$y = 3.21 - 0.006TURB$	0.207

Legend: A = all fish; L = large modal group; S = small modal group; T = temperature; TSQ = temperature squared; CON = conductivity; CONSQ = conductivity squared; DO = dissolved oxygen; TG = %-total gas saturation; TGSQ = %-total gas saturation squared; N_2 = %-nitrogen saturation; O_2 = %-oxygen saturation; TURB = turbidity; TURSQ = turbidity squared; CHR = COS(hour); SHR = SIN(hour); N.S. indicates lack of significance; I = March - May 1977; II = November 1977 - January 1978.

Atlantic croaker - Daily variation in both the mean depth of all the croaker and the mean depth of the large modal group of this species was significantly correlated with conductivity and turbidity. Mean depth of the small modal group was significantly correlated with temperature and time of day. Analysis of the large modal group gave the highest correlation coefficient (Table 2). The response of the large modal group to both conductivity and turbidity was non-linear. While the response of the large modal group to %-total gas saturation was not significant, the mean depth noticeably increased at saturations in excess of 116% (Fig. 5).

Black drum - Daily variation in both the mean depth using all fish and the mean depth of the large modal group of black drum was shown to be significantly correlated with temperature, conductivity, and %-total gas saturation. Mean depth of the small modal group was significantly correlated with %-nitrogen saturation and turbidity. For black drum the highest correlation was obtained by analyzing the large modal group (Table 2). A quadratic equation best described the responses of the large modal group of black drum to temperature and conductivity. The response of the large modal group to %-total gas saturation was linear (Fig. 6).

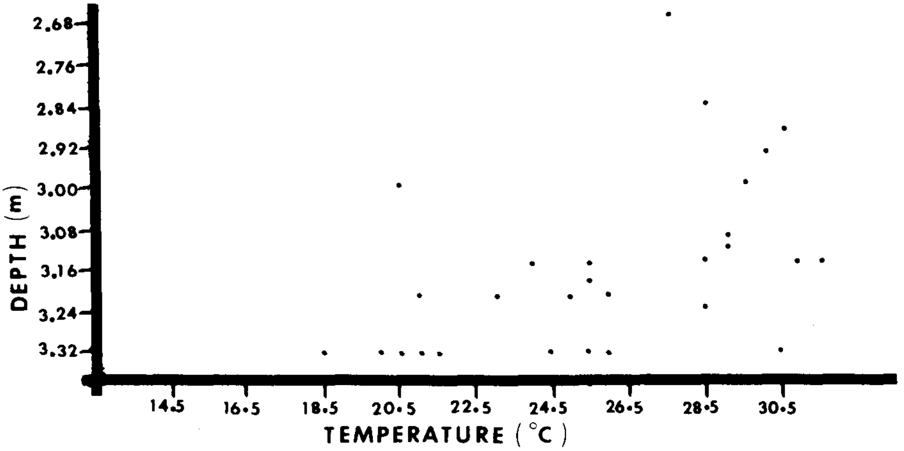

Fig. 2. Relationship between the mean depth of the small modal group of tarpon and temperature recorded daily between 1200-1500 hrs.

Diel variation in all the depth distribution components of black drum was significantly correlated only with time functions. The highest correlation was obtained by analyzing the large modal group (Table 2), and the relationship between this group and time was nonlinear (Fig. 7).

Striped mullet - Analysis showed that daily variation in the mean depth of all the striped mullet was significantly correlated with %-oxygen saturation. Mean depth of the large modal group was significantly correlated with %-total gas saturation and %-oxygen saturation, and mean depth of the small modal group was significantly correlated only with turbidity. The greatest amount of total daily variation in the depth distribution of the mullet was explained by analyzing the large modal group (Table 2). The response of the large modal group to %-oxygen saturation was linear, while the respone of the same group to %-total gas saturation was not (Fig. 8).

DISCUSSION

In a deep cage, fish can respond to a sudden change in an environmental parameter by moving to a depth where either the changing parameter is the most tolerable or conditions are best for physiological adaptation. It was assumed that the fish tested in this study would respond to changes in hydrological parameters in a predictable manner. Regression analysis of the variation in the depth distribution of each species against the hydrological data and the time functions did not, in general, explain a very high percentage of the total variation (Table 2). Additional factors must have therefore influenced the distribution of the fish within the cages, and at times altered their response to water quality. Fry (1971) stated that in an organism any entity that modifies the operation of another is defined as a masking factor. Sullivan and Fischer (1954) showed that light was a masking factor because changes in light intensity influenced temperature selection in speckled trout (*Salvelinus fontinalis*).

The multimodal distribution data that was often observed in all 5 species tested is an indication that social interaction influenced their distribution within the cage. For smallmouth bass (*Micropterus dolomieui*) and bluegill (*Lepomis macrochirus*), it has been shown that dominant individuals will prevent sub-dominants from entering the preferred area in a temperature-choice tank (Peek 1965; Beitinger and Magnuson 1975). In contrast, Strawn (1969), observing channel catfish (*Ictalurus punctatus*) in a

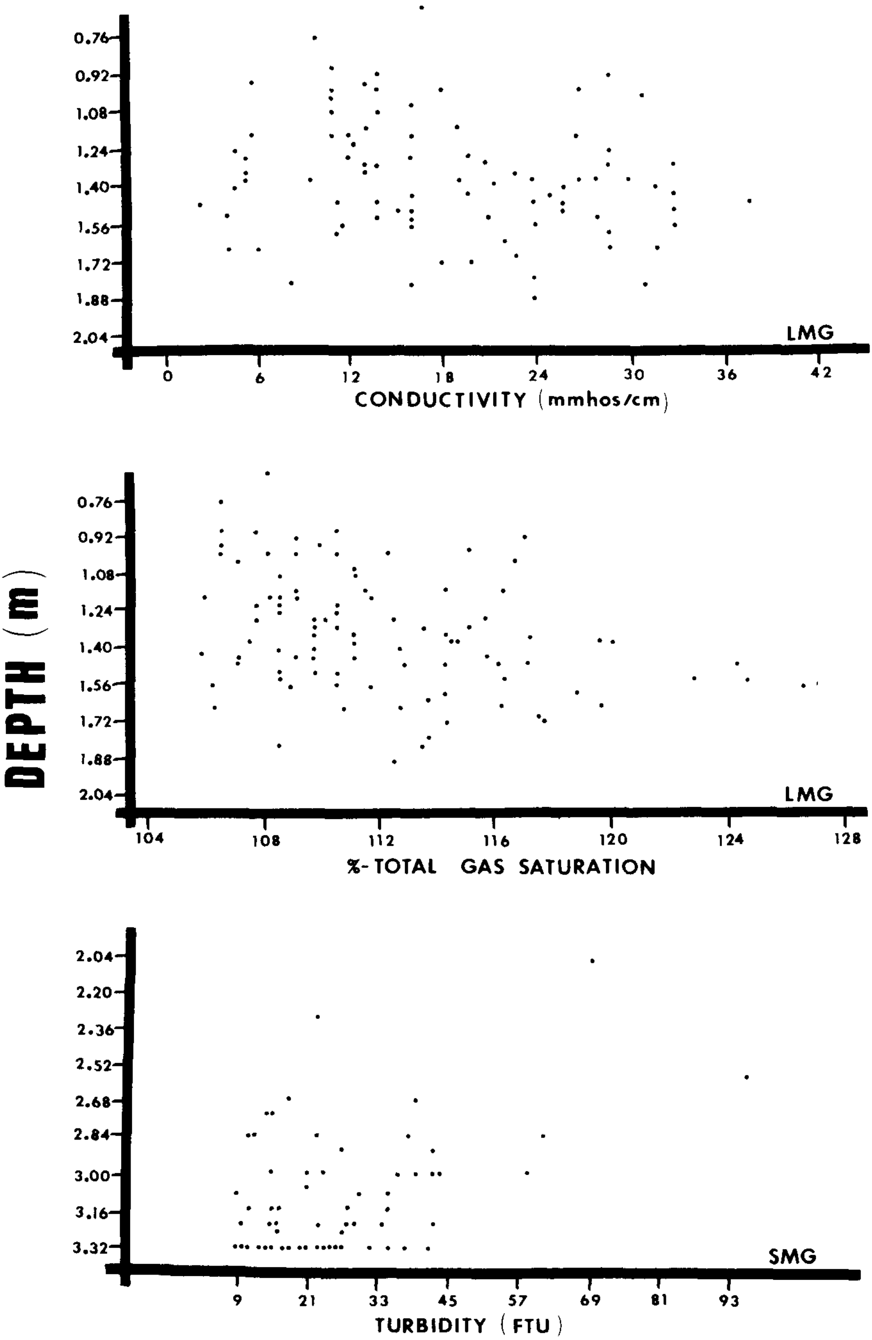

Fig. 3. Relationships between the mean depth of either the large or small modal group of pinfish and selected hydrological parameters recorded daily between 1200-1500 hrs. 'SMG' denotes small modal group; 'LMG' denotes large modal group.

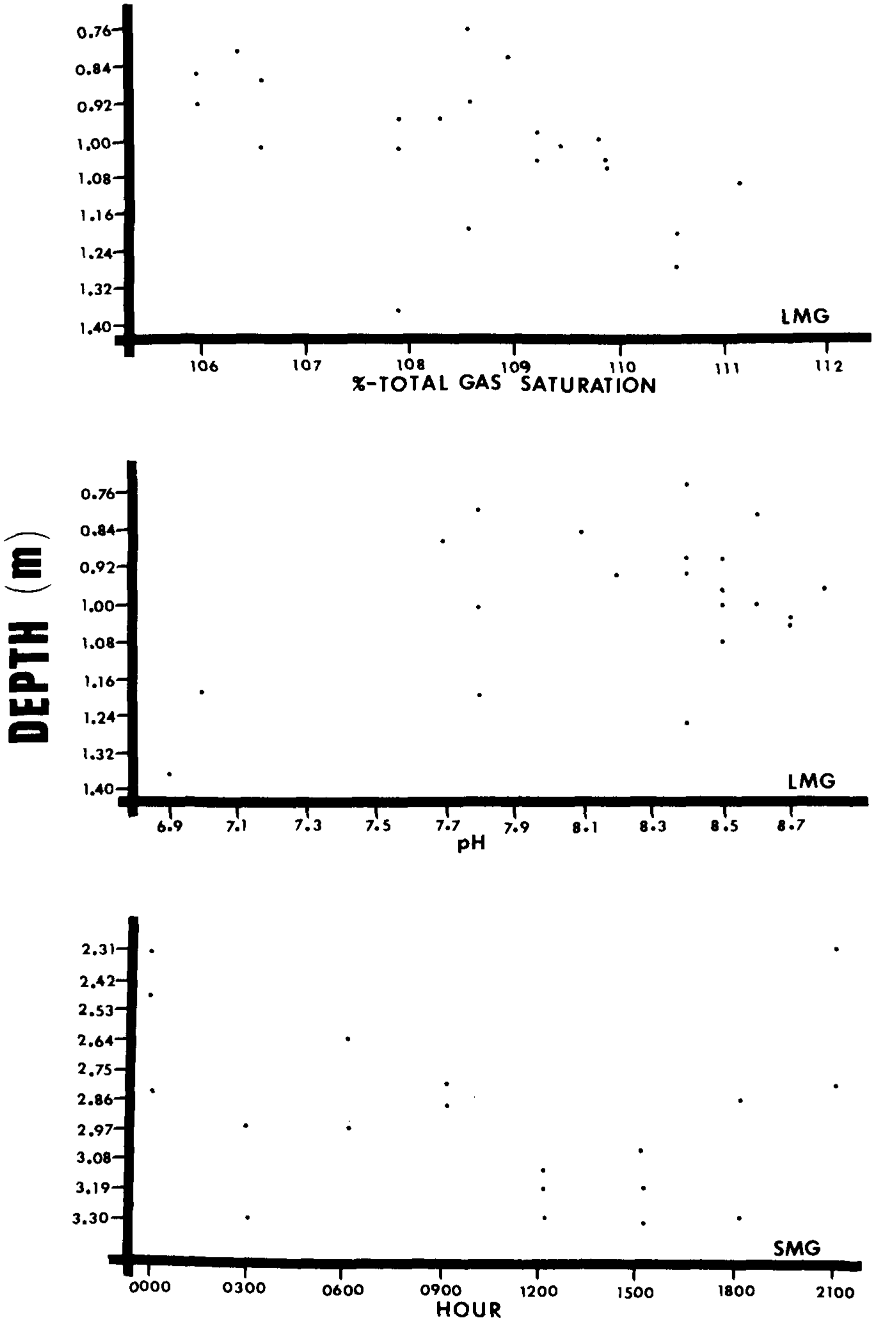

Fig. 4. Relationships between the mean depth of either the large or small modal group of pinfish and selected parameters recorded at 3-h intervals. 'SMG' denotes small modal group; 'LMG' denotes large modal group.

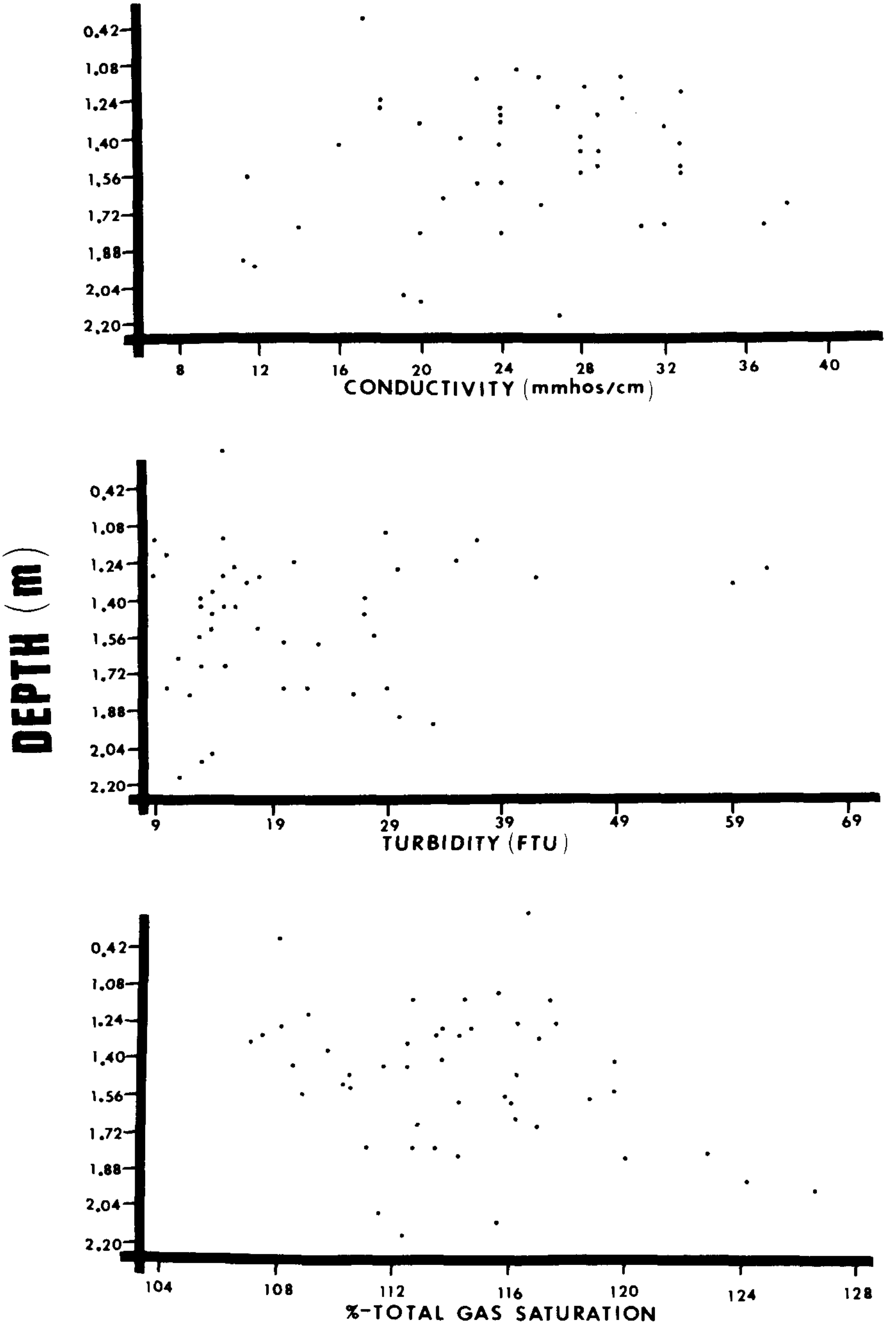

Fig. 5. Relationships between the mean depth of the large modal group of Atlantic croaker and selected hydrological parameters recorded daily between 1200-1500 hrs.

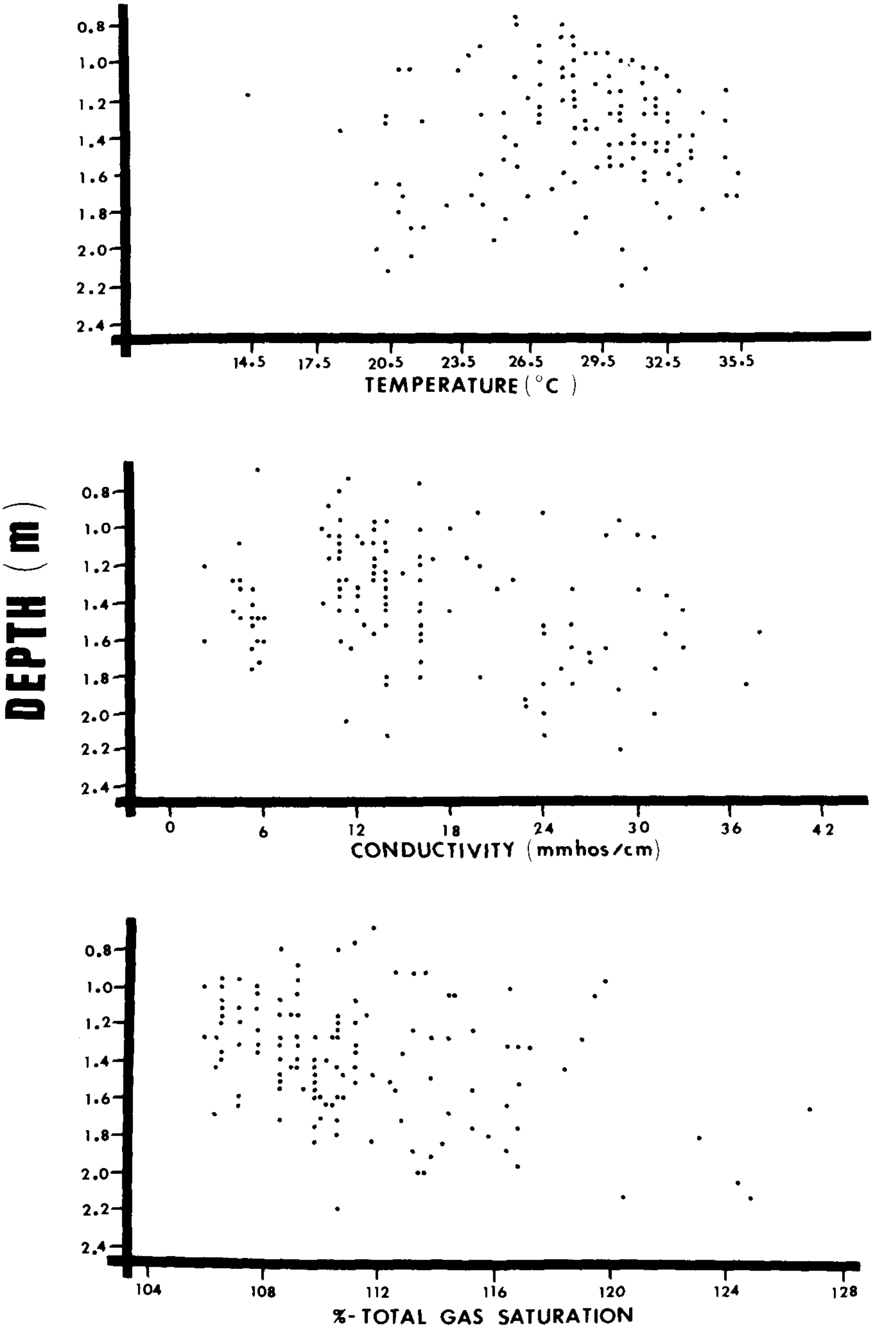

Fig. 6. Relationships between the mean depth of the large modal group of black drum and selected hydrological parameters recorded daily between 1200-1500 hrs.

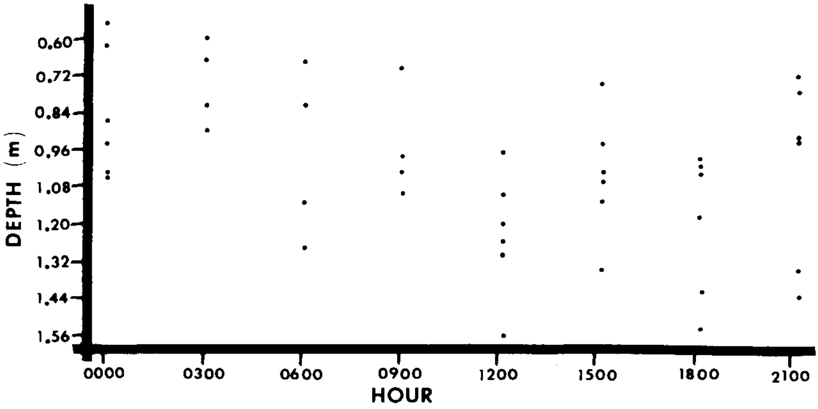

Fig. 7. Relationship between the mean depth of the large modal group of black drum and time recorded at 3-h intervals.

temperature gradient, reported that the majority of the fish aggregated at the preferred temperature while the small and sick fish were elsewhere. Obviously, before the data from this study can be fully analyzed, an estimate must be made as to what type(s) of social interactions occurred within the cage for each species.

Tarpon

For the tarpon depth distribution data, significant results were obtained only by analyzing the small modal group (Table 2), which would indicate aggression. However, Gibbard (1979) noticed no outright aggression or territorial behavior among tarpon held in aquaria, and Shlaifer and Breder (1940) reported that tarpon aggregate in the wild. A possible explanation for the discrepancy is that tarpon are air breathers (Hildebrand 1963). Occasional trips to the surface for air probably confounded the results.

The fact that tarpon are physostomous (open swim bladder) may account for the lack of a significant response to %-total gas saturation. Chamberlain et al. (unpublished manuscript) postulated an indirect mechanism for the detection of high gas saturation by physoclists (closed swim bladder). It was hypothesized that swim-bladder inflation caused an observed increase in buoyancy when Atlantic croaker (a physoclist) was exposed to gas-supersaturated water. This inflation may have been caused by back-diffusion into the swim bladder via the oval gland when gas pressure in the blood exceeded that in the bladder during high gas saturation. The only way a physoclist could immediately counteract increased buoyancy of this type would be to swim downward, compressing the bladder to neutral buoyancy volume. In contrast, if the swim bladder of a physostome inflates when it is exposed to supersaturated water, excess gas could be bled off via the pneumatic duct alleviating the necessity to swim downward to regain neutral buoyancy. Because physostomes do not have to swim downward to relieve excess swim-bladder pressure, the probability of contact with more highly saturated surface waters may increase. Salmonids (physostomes) more frequently survived periods of high gas saturation when allowed to sound to depth, but they did not always sound deeply enough to fully compensate for high levels of gas saturation (Ebel 1969; Dawley et al. 1976; Weitkamp 1976). Tarpon, however, may not be as adversely affected by high gas saturation as are salmonids, because of the air breathing adaptation of tarpon. Their blood probably is not in gaseous equilibrium with water during periods of supersaturation, therefore the probability of internal bubble formation may be reduced.

The relationship between the small modal group of tarpon and temperature (Fig. 2) may also be associated with their air-breathing adaptation. Johansen (1970) reported that

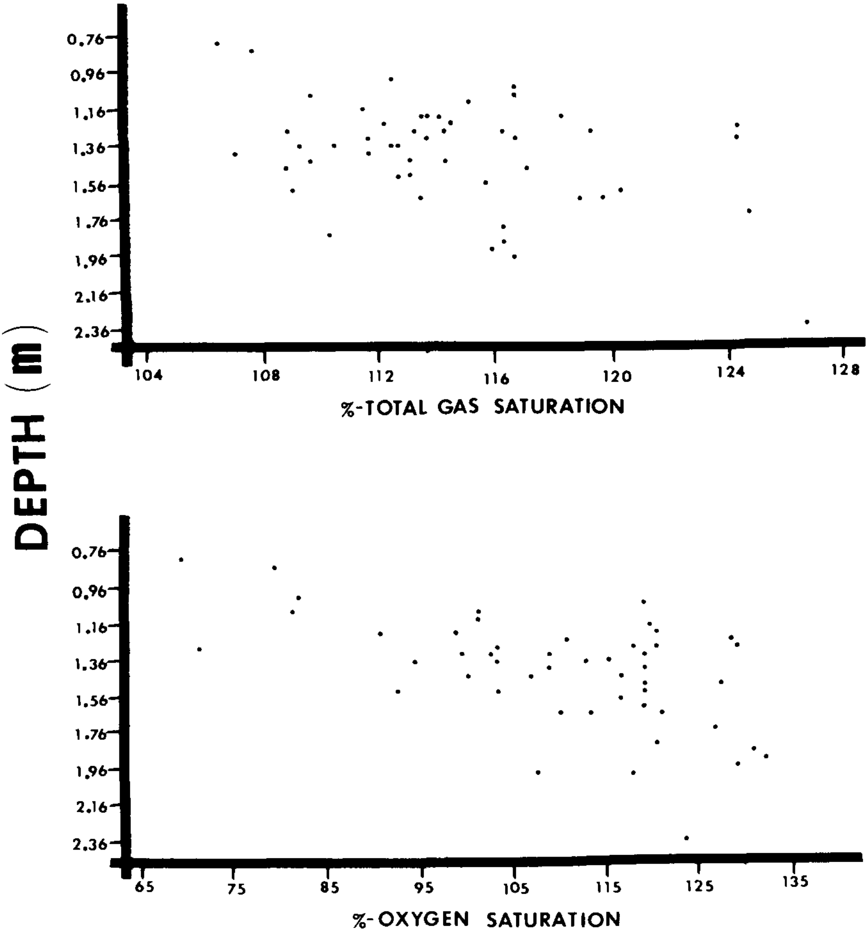

Fig. 8. Relationships between the mean depth of the large modal group of striped mullet and selected hydrological parameters recorded daily between 1200-1500 hrs.

the frequency of air breathing in fish generally increases with an increase in water temperature. Their upward movement with increased temperature may have been to shorten the distance to travel to breathe air. The lack of a significnt relationship between the depth of the large modal group and temperature was probably due to the fact that this group was usually close to the surface, and did not have as great a distance to travel for air as did the small modal group.

Pinfish

Caldwell (1957) and Gibbard (1979) observed extreme territorial and agonistic behavior in pinfish. This behavior could account for the sporadic appearance of 3 modal groups in the depth distribution of the pinfish. The large modal group probably represents sub-dominant individuals, but there is no way to determine which of the small modal groups represent the dominant fish. For this reason, the 2 small modal groups (when evident) were combined and analyzed as one. The greatest amount of daily variation in the depth distribution of the pinfish was explained by analyzing this small modal group (Table 2).

On a daily basis, the relationship between the mean depth of the small modal group of pinfish and turbibity was non-linear (Fig. 3). This was probably a reaction to changes in ambient light levels.

Daily variation in the large modal group of pinfish with respect to conductivity was non-linear (Fig. 3). At conductivities below 9 mmhos/cm (4.7 ppt), they probably were reacting to both conductivity and temperature, which was highest then (Fig. 1). One hypothesis that can be formed to explain the response of pinfish to conductivity levels above 9 mmhos/cm (4.7 ppt), is that general activity levels increase as conductivities varied in either direction from 22-23 mmhos/cm (12 ppt), which is close to being isosmotic with fish blood (Black 1957). At that point, their activity level was minimal. An alternate hypothesis is that the large modal group was responding to turbidity and its effect on the aggressive behavior of the dominant fish (small modal group). The small modal group moved up in the water column during periods of high turbidity (low conductivity), which could explain why the large modal group was high in the water column at that time. As conductivity increased and turbidity decreased, the small modal group went down in the water column, allowing the large modal group to sound to a more preferred light level. The upward response of the large modal group to further increases in conductivity may have been a reaction to an increase in aggression by the dominant fish as turbidity decreased and visibility improved. An increase in turbidity has been shown to reduce and alter both the activity level and social behavior in green sunfish (*Lepomis cyanellus*), a normally aggressive fish (Hemistra et al. 1969). Vinyard and O'Brien (1969) showed that either a decrease in light levels or an increase in turbidity caused a substantial reduction in the reactive distance of bluegill to all prey sizes. It is possible that both hypotheses are necessary to adequately explain the reaction of the large modal group of pinfish to conductivity.

The dominant individuals were generally deep in the cage where saturation values never reached critical levels, and this may explain the lack of a response by these fish to %-total gas saturation. In contrast, individuals in the large modal group were more shallow and exhibited a significant linear response to %-total gas saturation (Fig. 3). Although this group may not have been at the preferred depth during periods of high gas saturation, they were able to get deep enough to survive. Because pinfish are physoclists, they probably detect and avoid high gas saturation via changes in swim-bladder volume.

Although the greatest amount of diel variation in the depth distribution of pinfish was explained by analyzing the large modal group (Table 2), the effect of the dominant individuals on the distribution of the rest of the fish probably confused the results. A diel relationship between mean depth of the large modal group and pH is suspect, because pH did not exhibit any regular 24-h pattern. The relationship between mean depth of the large modal group and %-total gas saturation (Fig. 4) is probably a reaction to time of day instead of %-total gas saturation which varied on a 24-h basis, but was not high at that time. Mean depth of the small modal group was significantly related with time of day (Fig. 4), and the movements of these fish probably had the greatest influence on the depth distribution of sub-dominant individuals.

Atlantic croaker

Atlantic croaker are reported to be neither territorial nor aggressive in aquaria (Gibbard 1979). The greatest amount of daily variation in the depth distribution of the croaker was explained by analyzing the large modal group (Table 2), which indicates that croaker, as expected, did not display agonistic behavior.

Croaker, during periods of low conducitvity, responded in what appears to be a predictive manner (Fig. 5) by moving down in the water column to encounter water of higher salinity. The downward inflection at high conductivities may have been a reaction to light levels, which were highest at that time. The mean depth of the large modal group of croaker was significantly correlated with turbidity (Fig. 5), which indicates that they reacted to changes in ambient light levels.

Although the relationship between the mean depth of the large modal group of croaker and %-total gas saturation was not significant, a downward inflection in their distribution was observed at high saturations (Fig. 5). Generally, the croaker were deep enough in the water column to avoid supersaturation.

Black drum

Black drum apparently were not territorial because the greatest amount of variation in their distribution was explained by analyzing the large modal group (Table 2). This is consistent with the findings of Gibbard (1979) who reported that black drum exhibited schooling behavior in aquaria.

Daily variation in the mean depth of the large modal group of black drum was hyperbolic with respect to temperature. They were shallow at intermediate temperatures (Fig. 6). At temperatures above 22.0 C, the distribution could be explained by the concept of predictive thermoregulation. Although temperature was relatively uniform from surface to bottom, the past experience of both the individual and the species would dictate that cold water should be deep in the water column and warm water should be near the surface. At temperatures below 22.0 C, the black drum were probably responding to %-total gas saturation, which was highest then (Fig. 1).

With respect to conductivity, daily variation in the mean depth of the large modal group of black drum was hyperbolic (Fig. 6). Their depth increased as conductivity increased from 9-38 mmhos/cm (4.7-23.8 ppt). This is opposite to that which would be expected if they were seeking to predictively optimize conductivity levels, because surface waters are often less saline than bottom waters. A possible explanation for the observed distribution pattern is that the fish were responding to turbidity, which decreased as conductivity increased (Fig. 1). Diel observations of black drum revealed a strong 24-h cycle in their depth distribution (Fig. 7), indicating an orientation response to light levels. Because ambient light levels were highest during periods of high conductivity (low turbidity), they may have been seeking more favorable light levels by moving down in the water column. Because conductivity was less variable than, yet related to turbidity, the distribution data fit conductivity better. Below 9 mmhos/cm (4.7 ppt), the black drum were probably responding to both conductivity and temperature because temperature was high at that time (Fig. 1).

The linear response of black drum to %-total gas saturation (Fig. 6) indicates that black drum were capable of detecting and avoiding high gas saturation by sounding. As physoclists they probably detect supersaturated surface waters indirectly through an increase in swim-bladder volume and avoid GBD by swimming downward to compress the bladder to neutral buoyancy volume.

On a diel basis, mean depth of the large modal group of black drum was significantly correlated only with time functions (Table 2). The fish were deepest in the water column in the afternoon probably because they were responding to ambient light levels (Fig. 7).

Striped mullet

Results indicate that striped mullet were neither aggressive nor territorial because the highest correlation coefficient was obtained by analyzing the large modal group (Table 2). This is consistent with literature on striped mullet reporting schooling and unaggressive behavior (Darnell 1958; Gibbard 1979).

Although the relationship between the mean depth of the large modal group of mullet and %-total gas saturation was non-linear (Fig. 8), a threshold response is not indicated because the depth appears to gradually increase at a constant rate. As physoclists, striped mullet probably respond to %-total gas saturation when a change in buoyancy is noticed.

The significance of the linear response of the large modal group of striped mullet to %-oxygen saturation (Fig. 8) indicates that they are sensitive to dissolved oxygen. As a relatively active fish (Gibbard 1979), mullet probably require large amounts of oxygen. Mullet have been reported to feed on matter in the surface film (Darnell 1958), and may be able to utilize the increased oxygen available at the air/water interface during periods of low dissolved oxygen. At high levels of %-oxygen saturation, they were probably responding to %-total gas saturation which varies proportionately with %-oxygen saturation.

SUMMARY

Overall trends in the distribution data suggest that pinfish, Atlantic croaker, and black drum react to ambient light levels. This reaction was especially evident in the diel distribution patterns of black drum and pinfish. The effects of light on the distribution of these fish may have masked to a degree the effects of the hydrological parameters on their distribution. Pinfish, black drum, and striped mullet were observed to be able to detect and avoid supersaturated surface waters by sounding. Atlantic croaker did not significantly respond to %-total gas saturation, however, they typically stayed deep enough in the water column to be free of GBD. Tarpon did not appear to react to %-total gas saturation in any fashion. It is likely that they can not detect supersaturated waters because, as physostomes, they can release excess swim-bladder gas during periods of supersaturation through the pneumatic duct. In contrast, a physoclist can only immediately alleviate increased buoyancy caused by excess swim-bladder gas by swimming downward compressing the bladder to neutral buoyancy volume. Most likely, physoclists avoid GBD mortality in this manner. Tarpon did not react to gas supersaturation in deep cages and might not have died if kept in shallow cages because they are air breathers. In order to more fully test the hypothesis of the implication of the swim bladder in avoiding GBD mortality, it will be necessary to monitor the distribution of a physostome that does not breathe air. Sea catfish (*Arius felis*) would be ideal for this purpose in the Cedar Bayou system. Trends in the distribution data also showed that 1) black drum and tarpon reacted to temperature; 2) Atlantic croaker reacted to conductivity; and 3) striped mullet reacted to %-oxygen saturation.

Information on the general depth preferences of the fish tested in this study is of value for the evaluation of surveys in which collecting gear sampled a known portion of the water column. The fish usually occupied mid-water depth levels, indicating that surface or bottom collecting gear might not give as representative a sample as would mid-water collecting gear. The diel movements of pinfish and black drum indicate that nets should be used at different depths during different portions of a 24-h period. The constricting nature of the cages, degree of crowding, and interaction between the fish, however, may have influenced their depth distribution in cages. Also, food sluicing through the cages may have been differentially available with depth, influencing the depth distribution of the fish. For future experiments, greater or smaller stocking densities than those used in this study could change the social interactions of the fish and give different depth distribution patterns. Ideally, visual observation of the fish would enable the investigator to determine the effects of social interactions on the depth distribution of fishes, and to see if food was differentially available with depth.

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