Temperature Selection and Vertical Distribution of Striped Bass During Lake Stratification

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Abstract: Water temperature appeared to be a major factor influencing the distribution of striped bass (*Morone saxatilis*) during 1978 in Lake Norman, North Carolina, while size of striped bass, dissolved oxygen concentrations, available forage, and current also had some influence on their distribution. Large striped bass [$\geq$ 400 mm TL) appeared to be more restricted to the cooler waters than small striped bass (< 400 mm TL) when water temperature exceeded 17.0° C and stratified conditions existed. These factors should be considered when establishing or managing a striped bass fishery in a reservoir or lake.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 37:276–286

Striped bass have been introduced into many southern reservoirs as a sport fish and as a predator for abundant clupeid populations (Bailey 1975). However, management of striped bass fisheries in reservoirs has not been without problems. Summer die-offs of striped bass, particularly of large individuals, have occurred in several reservoirs (Mathews and Hill 1982). Studies on temperature selection of striped bass in Cherokee Reservoir, Tennessee, support the hypothesis that mortalities of striped bass larger than 5 kg were associated with their intolerance to warm water temperatures and to low dissolved oxygen levels that they were forced to inhabit (Waddle et al. 1980, Schaich and Coutant 1980, Coutant and Carroll 1980).

Striped bass were first introduced into Lake Norman, North Carolina, in 1966 with annual stockings since 1968. Subsequently, catches of emaciated striped bass during late summer and fall have been reported by fishermen and personnel conducting environmental monitoring programs on Lake Norman. Lewis et al. (1977) found several dead striped bass and collected live individuals during the late summer and fall of 1975 on Lake Norman with severe infestation of *Epistylis* sp. They hypothesized that infestation of *Epistylis* sp. and probable bacterial infections could have resulted from stress on striped

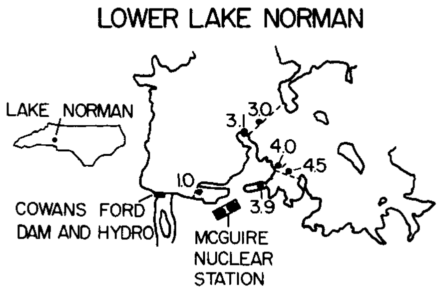

Figure 1. Map showing limnetic Locations 1.0 (intake at MNS), 3.0, 3.9 (discharge at MNS), and 4.5 and littoral Locations 3.1 and 4.0 sampled with vertical gill nets from December 1977 through November 1978 on lower Lake Norman, North Carolina. Dashed lines indicate echogram transects.

bass. Waddle et al. (1980) found *Epistylis* sp. and bacterial infections on many, but not all, dead or dying striped bass examined in Cherokee Reservoir, Tennessee.

Lake Norman, a 13,156 ha hydro-electric impoundment and cooling reservoir for fossil and nuclear power stations, was formed in 1963 with the completion of Cowans Ford Dam on the Catawba River. Lower Lake Norman has been intensively sampled since 1973 to determine impact of McGuire Nuclear Station (MNS) on Lake Norman (Siler et al. 1981). The first of 2 units began commercial operation in 1982. As a part of monitoring programs, this study was implemented to determine the vertical distribution and water temperatures selected by fish before and during operation of MNS. Only the preoperational phase of this study has been completed, and striped bass was the most common species collected.

Seasonal shifts in distribution of striped bass were noted, and the objectives of this paper are to describe these shifts and to explain them according to the following hypotheses: (1) shifts in distribution of striped bass occurred as a result of changes in water temperature and dissolved oxygen concentrations, (2) such shifts were related to the size of striped bass, and (3) these shifts manifested changes in food habits. Management implications of changes in distribution are discussed.

The author acknowledges B. K. Baker, D. W. Sherrill, and J. R. Siler for their assistance in collecting and processing fish, S. D. Moore for drawing figures, and J. A. Brotherton for typing the manuscript.

Methods

Vertical gill nets were set for 4 days during the third week of each month at limnetic Locations 1.0 (MNS intake area), 3.0, 3.9 (MNS discharge area), and 4.5, and at littoral Locations 3.1 and 4.0 (Fig. 1) from December 1977 through November 1978. All nets fished the entire water column from surface to bottom at each location. At littoral locations, nets were set at an approximate depth of 3 m, irrespective of water surface elevation of Lake Norman. The depth of nets at limnetic locations varied with water level of Lake Norman. The average depth at Locations 1.0, 3.0, 3.9, and 4.5 during the study was 16, 19, 9, and 17 m, respectively.

Five gill nets were fished at each location using 2 roller floats. Each roller float was constructed of PVC pipe 0.1 m in diameter and 5.3 m long with the ends capped. Gill nets consisted of monofilament webbing with a square mesh size of either 1.3, 2.5, 3.3, 5.1, or 7.6 cm. Three nets with a respective mesh size of either 1.3, 2.5, or 7.6 cm and widths of 1.9, 1.9, and 1.5 m were attached side by side to 1 roller-float; 2 nets with a mesh size of either 3.3 or 5.1 cm and each 2.5 m wide were attached to the other roller-float. The length of nets used at littoral locations was 4.6 m and at limnetic locations, 21.3 m. When setting nets at all locations except Location 3.1, the 2 roller-floats were connected by a line approximately 1 m long, and roller-floats were secured in position with anchor lines. At Location 3.1, each roller-float was secured by anchor lines with an approximate distance of 25 m between floats, so that all nets set at Location 3.1 would be at a depth of 3 m. It was not necessary to separate the 2 roller-floats at Location 4.5.

Nets were set and checked daily (weather permitting) using a retrieval system similar to that of Lackey (1968). Each net was marked at 1-m intervals from the bottom of the net. Catch rates were expressed as the number of fish collected/month (96 hours of gillnetting) at each 1-m depth interval at each location. The total monthly catch at each location was the summation of the catches among all depths. To determine water temperature and dissolved oxygen concentration selected by striped bass the percent of the total number of striped bass caught at a temperature or oxygen level was compared to the percent of the total gill net effort at a certain temperature or oxygen level. The percent of gill net effort at a specific temperature or oxygen level was a function of the total number of 1-m depth intervals at which these water quality variables were measured. Total length of each fish (mm) and depth of capture (m) were recorded. Contents of stomachs were examined, and the food item(s) composing the highest biomass (major food item) and second highest biomass (minor food item) were estimated, either macroscopically or microscopically.

A Hydrolab Model TDO_2 was used to measure water temperature (°C) and dissolved oxygen concentration ($mg \cdot l^{-1}$) at 0.3 m below the surface and at 1-m intervals from the surface to the bottom, when the nets were checked. Light intensity (Langleys) and turbidity (NTU) were recorded monthly at each location between 1,300 and 1,500 h. A Montedoro Whitney light meter was used to measure light intensity at 0.3 m below the surface and at 1-m intervals from the surface until either no light was measured or the bottom was reached. A Monitek (Model 150) turbidimeter was used to measure turbidity in water samples taken at 0.3-m and at 5-m intervals from the surface to 1 m above the bottom. For additional information on vertical distribution and inference of diurnal movements of fish, a Ross fine line chart recorder (Model

5200B) was used to make monthly echograms during day and night along 2 transects parallel to each net at the limnetic locations (Fig. 1).

Results

A total of 597 fishes representing 15 species was collected from December 1977 through November 1978. Catches of fish were lowest in winter and early spring and 65% of the total catch occurred from July through September (Fig. 2). Striped bass was the most abundant species, followed by gizzard shad (*Dorosoma cepedianum*) and threadfin shad (*Dorosoma petenense*), composing 45, 20, and 12% of the total catch, respectively. However, catches of gizzard shad, threadfin shad, and other species besides striped bass were either low or infrequent (Fig. 2).

Striped bass were collected during all months except February. From March through May, striped bass were collected from the warmer waters (primarily surface to 5m), with a small pulse in striped bass catches occurring at littoral locations in April and May. Average surface water temperatures among locations increased from 17.0° C in May to 24.5° C in June (Fig. 2). Most of the striped bass collected in June were from the cooler waters of the metalimnion. From July through September, catches of striped bass were highest in August and occurred mainly in the metalimnion at all limnetic locations except at the unheated discharge of MNS (Figs. 2 and 3). By October, overturn of Lake Norman had occurred and catches of striped bass were low.

Catches of striped bass at the unheated discharge of MNS (Location 3.9) during August were concentrated from 4 m to the bottom (Fig. 3), as were striped bass collected in July and September. During these three months, water temperatures and dissolved oxygen concentrations were uniform throughout the water column. Water temperature during July, August, and September averaged 24.0°, 26.0°, and 24.0° C, respectively, while oxygen concentrations were 6.3°, 5.3°, and 6.1 $mg \cdot l^{-1}$, respectively. These conditions were the result of pumping unheated condenser cooling water for testing equipment at MNS. Prior to pumping, which began in July and continued through the remainder of the study, stratified conditions existed at the discharge location. The discharge of MNS was the only location where an appreciable flow existed (approximately 40 $m^3 \cdot s^{-1}$ during pumping).

The vertical profiles of water temperature and dissolved oxygen concentration at Locations 1.0 (intake of MNS), 3.0, and 4.5 were similar in July, August, and September. The greatest vertical thermal gradient occurred in August (Fig. 3). Although catches of striped bass at these locations were low in July ($N = 15$ fish), all but 1 striped bass were collected from 8 to 11 m. In July, water temperatures at these depths ranged from 20.0° to 23.5° C and dissolved oxygen concentrations ranged from 2.4 to 4.9 $mg \cdot l^{-1}$. In August, 5 striped bass were collected at depths from 1 to 5 m, while 57 fish were concentrated at depths from 6 to 11 m. Water temperatures and dissolved oxygen concentrations during August were essentially uniform from surface to 6 m, while from 6 to 11 m temperatures ranged from 24.0° to 27.5° C and oxygen concentrations ranged from 0.2 to 7.0 $mg \cdot l^{-1}$ (Fig. 3). Catches declined to 5 striped bass in September, with 4 striped bass caught below 10 m. Water temperatures and dissolved oxygen concentrations in September ranged from 21.5° to 26.0° C and from 3.0 to 4.1 $mg \cdot l^{-1}$, respectively.

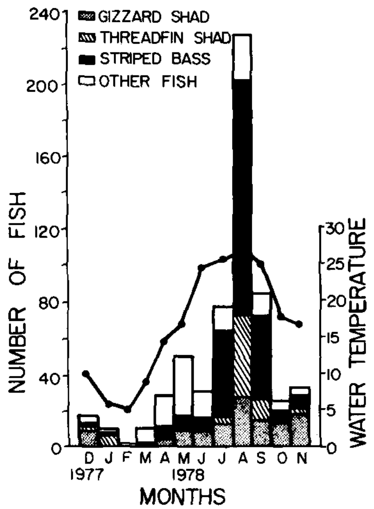

Figure 2. Total number of fish collected with vertical gill nets on lower Lake Norman, North Carolina. The solid line is the mean water temperature (°C) taken monthly near the surface (0.3 m) of each location.

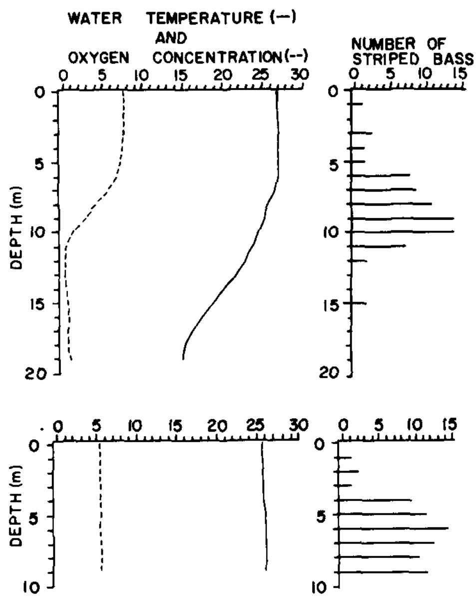

Figure 3. Mean water temperatures (°C) and dissolved oxygen concentrations ($mg \cdot l^{-1}$) that occurred in August 1978 at Locations 1.0, 3.0, and 4.5 (upper graph) and at Location 3.9 (lower graph) on lower Lake Norman, North Carolina. The number of striped bass collected in gill nets at these locations is represented in the histogram to the right of each graph.

A high ratio of percent catch of striped bass to percent of gill net effort indicated that striped bass selected areas where specific water temperatures (°C) and dissolved oxygen concentrations ($mg \cdot l^{-1}$) occurred at limnetic locations during July and August (Figs. 4 and 5). Striped bass appeared to select areas where water temperatures of 20° to 24° C occurred in July and water temperatures of 24° to 26° C occurred in August (Fig. 4). Striped bass appeared to select areas where dissolved oxygen concentrations of 4 and 5 $mg \cdot l^{-1}$ occured in July and areas where oxygen levels of 3 to 6 $mg \cdot l^{-1}$ occurred in August.

Most striped bass were collected at depths corresponding to low light intensity (<0.03 Langleys) from July through September. However, because light intensity was not independent of water temperature and nets were only

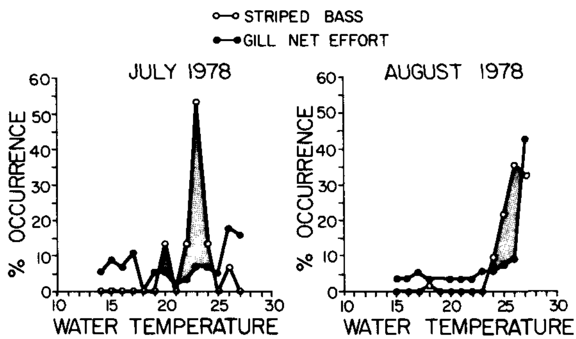

Figure 4. Percent of striped bass collected at a specific water temperature (nearest °C) and percent of gill net effort at a particular water temperature that occurred at Locations 1.0, 3.0, and 4.5 on lower Lake Norman, North Carolina. The shaded area represents a high ratio of percent catch of striped bass to percent of gill net effort.

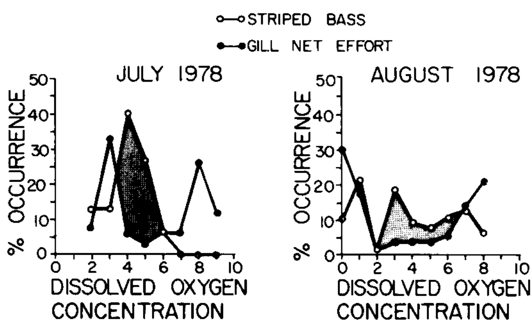

Figure 5. Percent of striped bass collected at a specific dissolved oxygen concentration (nearest $mg \cdot l^{-1}$) and percent of gill net effort at a particular oxygen concentration that occurred at locations 1.0, 3.0, and 4.5 on lower Lake Norman, North Carolina. The shaded area represents a high ratio of percent catch of striped bass to percent of gill net effort.

Table 1. Number of striped bass (*Morone saxatilis*) having food items in their stomachs during 1978 on Lake Norman, North Carolina. Major represents the food item that was visually estimated to have the highest biomass. Minor represents the food item that was visually estimated to have the second highest biomass.

Locations	Food items	July Major	July Minor	August Major	August Minor	September Major	September Minor
1.0, 3.0, and 4.5	*Hexagenia* spp.	0	1	32	3	0	0
	Chaoborus spp.	0	0	1	1	0	0
	Dorosoma petenense	0	0	3	0	1	0
	Dorosoma spp.	10	0	7	3	0	0
	Lepomis spp.	0	1	1	0	0	0
	Perca flavescens	1	0	4	0	1	0
	Fish remains	0	0	3	0	1	0
	Empty	4	13	13	57	2	5
3.9	*Hexagenia* spp.	0	0	3	4	0	0
	Chaoborus spp.	4	1	26	1	3	1
	Dorosoma petenense	0	0	7	0	0	0
	Dorosoma spp.	19	0	2	0	1	0
	Lepomis spp.	0	0	0	0	0	0
	Perca flavescens	1	1	2	2	3	0
	Fish remains	4	1	11	1	4	0
	Empty	5	30	20	63	31	41

checked once during the day, the response of striped bass to light intensity could not be described. Although no species identifications were possible, echograms showed diurnal differences in the distribution of fish with aggregations of fish present during the day and dispersal of fish at night.

No relationship between the vertical distribution of striped bass and turbidity levels was apparent. Turbidity levels were low and essentially uniform throughout the water column.

Striped bass collected in gill nets ranged from 192 to 710 mm total length (TL). The distribution of striped bass collected from July through September at the limnetic locations varied with the size of the fish. The mean total length of striped bass that were collected at each depth in the MNS discharge and from surface to 5 m at the other locations ranged from 327 to 386 mm, while that of striped bass caught at depths below 5 m at locations other than the MNS discharge ranged from 404 to 587 mm (Fig. 6). The majority of striped bass ≥400 mm TL were collected at locations having a thermal gradient. Of the 54 striped bass ≥400 mm TL collected at Locations 1.0, 3.0, and 4.5, all were collected below 5 m, and only 7 fish occurred at 27° C (Figs. 6 and 7). The 7 fish were collected from depths of 6 and 7 m, just above the thermocline in August (Figs. 3 and 6). Striped bass <400 mm TL were collected throughout the water column in August with 13 of 25 fish occurring at 27° C at Locations 1.0, 3.0, and 4.5. Both small (<400 mm TL) and large ((≥400 mm TL) striped bass were most abundant from 24° to

26° C among all locations, while 3 small striped bass and 12 large striped bass were collected from 18° to 23° C water temperatures.

Food items consumed by striped bass differed among months and between the discharge location and other limnetic locations in August (Table 1). No difference in food items consumed occurred among depths at each location. In July, shad (*Dorosoma* spp.) was the primary food item in the stomachs of striped bass at all locations (Table 1), but no threadfin shad or juvenile gizzard shad were collected in nets. In August, high catches of threadfin shad and striped bass occurred at similar depths in the MNS discharge, while at other locations only 5 of the 64 striped bass collected occurred in the epilimnion where threadfin shad were collected. When fish were not present in the stomachs of striped bass from the MNS discharge in August, the larvae

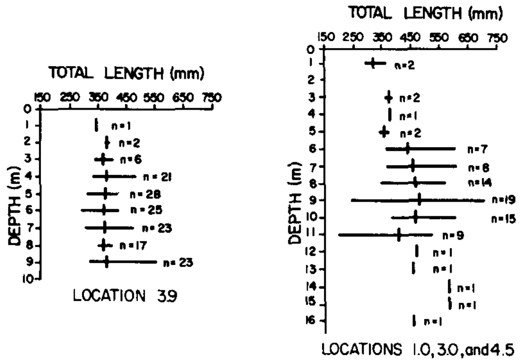

Figure 6. Mean (vertical bar) and range (horizontal bar) of total lengths of striped bass collected from July through September 1978 at Locations 1.0, 3.0, 3.9, and 4.5 on Lake Norman, North Carolina.
n = number of fish collected.

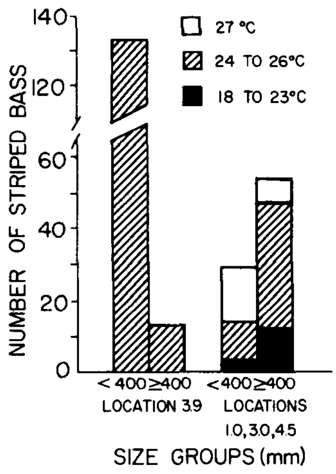

Figure 7. The number of striped bass collected from July through September according to size groups of total lengths (mm) at Locations 1.0, 3.0, 3.9, and 4.5 on Lake Norman, North Carolina. The number of striped bass collected at water temperatures of 27°, 24° to 26°, and 18° to 23 °C are represented by the blank, the slanted line, and the solid portion of each bar, respectively.

and pupae of *Chaoborus* spp. were the major food items found. Mayfly nymphs (*Hexagenia* spp.) were the major food items in stomachs at locations other than the discharge during August. In September, fish and *Chaoborus* spp. larvae and pupae were found in the few stomachs of striped bass containing food.

Discussion

Catches of fish in gill nets depend on the activity, size, and species of fish (Lambou 1962, Moyle and Lound 1960), as well as the influence of environmental variables (Berst 1961). Temporal occurrence and distribution of fish in gill nets in this study appeared to be strongly related to the response of fish to water temperature and the size and species selectivity of the nets.

The rise in mean surface water temperature from 17.0° C in May to 24.5° C in June influenced a shift in the distribution of striped bass from the warmer waters (primarily from surface to 5 m) to the cooler waters of the metalimnion. Coutant and Carroll (1980) reported a similar shift in the distribution of striped bass from April through October when water temperatures exceeded 21° C. Striped bass collected during June and July from Lake Norman generally occupied similar water temperatures as those reported by Coutant and Carroll (1980); however, striped bass collected during August from Lake Norman occupied warmer water (24.0° to 27.5° C) and were likely forced to do so because of anoxic conditions at cooler water temperatures. The distribution of striped bass studied by Coutant and Carroll (1980) was unaffected by dissolved oxygen, which never dropped below 7.0 $mg \cdot l^{-1}$ at their study site.

Movement of striped bass to spring-fed refuge areas in Cherokee Reservoir during late summer in response to increasing water temperature and decreasing dissolved oxygen was observed by Waddle et al. (1980), Coutant and Carroll (1980), and Schaich and Coutant (1980). The discharge of MNS in Lake Norman served as a refuge for large numbers of striped bass from July through September. However, the water temperature, dissolved oxygen concentration, and flow occurring in the discharge during these 3 months appeared to attract proportionately larger numbers of the smaller striped bass (<400 mm TL). Striped bass 400 mm TL or larger were collected primarily at the other locations from depths that had water temperatures either similar or slightly cooler than that at the discharge location, while smaller striped bass occurred predominantly at water temperatures either similar or slightly warmer than that at the discharge location. Thus, an interrelationship of water temperature and size or age of striped bass appears to influence the vertical distribution of striped bass. Schaich and Coutant (1980) tagged striped bass weighing from 2 to 5 kg and observed that the older fish seemed to prefer cooler temperatures than the younger fish. Only 9 of 268 striped bass collected in this study weighed as much as 2 to 4 kg. However, larger striped bass exist in Lake Norman, as 5.6% and 6.7% of the estimated striped bass harvest from unpublished creel surveys in 1978 and 1982, respectively, were striped bass 4 kg or larger.

The possibility that feeding behavior also influenced the distribution of smaller striped bass (<400 mm TL) at the discharge location and in the epilimnion at the other limnetic locations could not be discounted. The vertical distribution of threadfin shad in August coincided with that of smaller striped bass, which fed on threadfin shad. The occurrence of food items besides shad (i.e., yellow perch and mayfly nymphs) in the stomachs of striped bass collected at the cooler water temperatures indicated that a food source may have existed for striped bass in the metalimnion. Although the distribution patterns of large striped bass (≥400 mm TL) and adult gizzard shad that could be consumed by striped bass (Jenkins and Morais 1976) overlapped during the year, adult gizzard shad did not occur in striped bass stomachs.

Considering the general agreement in the response of striped bass to changes in water temperature and anoxic conditions between Lake Norman and Cherokee Reservoir, the potential for problems in management of the striped bass fishery in Lake Norman and other cooling reservoirs or lakes seems apparent. Sitings of moribund, emaciated, or diseased large striped bass on Lake Norman during late summer and fall indicate that adequate habitat to support all large striped bass may not have been available at times. *Epistylis* sp. and fungus infestations were observed on striped bass 400 mm TL and larger collected in October and November 1978, but no moribund striped bass were found. Coutant (personal communication) suggested that lakes without temperatures below about 22° C in well-oxygenated zones will be unsuitable for striped bass larger than 5 kg. Such conditions did not exist at the study site on Lake Norman in August 1978 but could have existed at other areas of Lake Norman. If conditions in other areas of Lake Norman were similar to those found in lower Lake Norman during August 1978, striped bass of 5 kg or larger would have inhabited either waters with oxygen concentrations less than 0.5 $mg \cdot l^{-1}$ or waters with temperatures greater than 22° C. Obviously, under either set of conditions, suitable habitat of large striped bass was reduced in Lake Norman. Thus, fishery managers for Lake Norman, as well as those for other lakes where a striped bass fishery is to be established or managed, should base management decisions on the amount of suitable habitat, the available forage base, and whether the distribution of striped bass coincides with that of forage fish.

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