THE EFFECTS OF A HALOCLINE ON FISH DISTRIBUTION IN THE RED RIVER ARM OF LAKE TEXOMA

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Annual stratification in Lake Texoma begins with a salinity barrier restricted to the Old Red River Channel. Subsequently the hypolimnion covers much of the old river bottom land and the halocline may be reinforced by a thermocline. Depletion of dissolved oxygen in the hypolimnion may force most fishes to live in the epilimnion.

A variety of physico-chemical factors influence fish productivity in lakes, and it is possible to make reasonable predictions of fish harvest based on the morphoedaphic index (1). The morphoedaphic index seems applicable to reservoir fish production (2) but substitution of thermocline depth for mean depth provides better fit. Consequently, extent and depth of reservoir stratification should be determined as it may have a significant impact on fishing quality, especially when stratification causes an anoxic hypolimnion.

Water stratification may result from differences in temperature or amounts of dissolved solids, both of which may result in water of differing specific gravity. Although classic limnology may emphasize thermal factors in stratification, concentrations of dissolved solids may cause greater differences in specific gravity than those associated with a thermocline (3). Each causal factor is associated with climatic circumstances, and the stability of stratification depends upon rates of summer warming or changes in concentrations of dissolved solids in the inlet water. We were stimulated to determine whether Lake Texoma stratifies by a 1970 communication from Andrew Robertson to the senior author which stated that Lake Texoma had a halocline that separated an anoxic hypolimnion from an oxygen-containing epilimnion by different amounts of dissolved solids. Unfortunately, Dr. Robertson did not publish his results and his data are not available. Our investigations show that (in 1974 at least) the primary cause for stratification on the Red River Arm of Lake Texoma was concentrations of dissolved solids which can cause a virtually anoxic hypolimnion prior to establishment of thermocline at the same depth as the halocline.

Fish abundance and diversity are associated with dissolved oxygen. Gill nets set below the halocline in the Red River Arm of Lake Texoma took fewer fishes than those set in similar locations above the hypolimnion. As the halocline rose to cover an established gill net station, the numbers of fish taken were reduced.

MATERIALS AND METHODS

Water samples were obtained with a 2.3-liter Kemmerer Water Sampler. Physico-chemical parameters were determined by standard methods (4): dissolved oxygen by the azide modification of the Winkler method (and on occasion by Hach kit titrations); chlorides by the argentometric method; total dissolved solids (TDS) with a Myron L Dissolved Solids Meter model 532 T1; and water temperatures were obtained by a meter and probe supplemented by glass thermometer readings. Bottom profiles were outlined with a Bendix DR-19 depth recorder supplemented and/or calibrated by soundings (often by use of the Kemmerer Water Sampler on a calibrated rope).

Fishes were obtained with 91.4 × 1.8 m gill nets with 5-cm stretch mesh. Nets were set on the bottom at 16.5, 12.5, 8.8, and less than 5 m depth as well as suspended at 12.5 m at Station C (Figure 1).

FIGURE 1. Collection stations in Lake Texoma (water depth at sampling times in July in parentheses): A) Hauani Creek (5 m); B) Briar Creek (10 m); C) off OUBS — and the adjacent Buncombe Creek — (17 m); D) west end of Islands (16 m); E) east end of Islands (20 m); F) Preston Point (23 m); G) Washita Point (25.5 m); H) Sunset Camp (26 m); I) Cartwright (26 m).

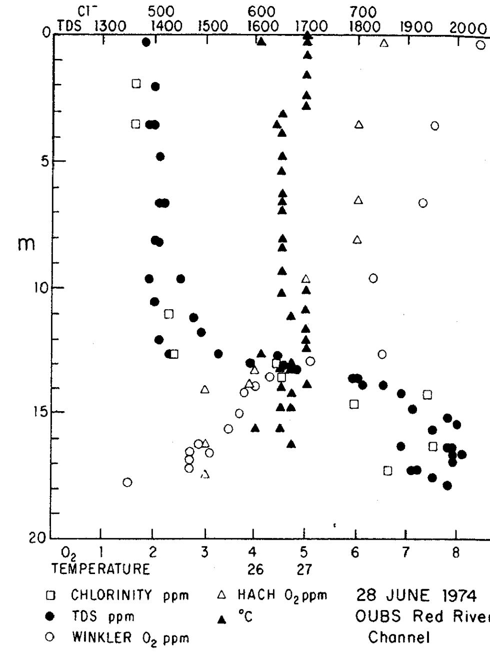

FIGURE 2. Thermal and chemical measurements from Lake Texoma near the junction of the Old Red River and Buncombe Creek channels 28 June 1974.

RESULTS

We obtained profiles of temperature, dissolved solids, and dissolved oxygen at one or more locations in Lake Texoma on 7, 11, 25, 28 June, and 2, 9, 10, 11, 12, 16, 17, 18, 19 July. Every profile had reduced oxygen concentrations at the bottom and the dissolved oxygen and solids negatively associated with each other. During June we found no thermal gradient that could account for the reduction of oxygen with depth. To confirm that dissolved solids caused stratification we sampled extensively on 28 June from a station at 18 m depth (Figure 2) in the Old Red River Channel near the entrance of the Buncombe Creek Channel and adjacent to the University of Oklahoma Biological Station (hereafter, locations between Buncombe Creek and the Willis Bridge for US 377 will be called "off UOBS"). All titrations were made of water samples obtained in varied sequences (*i.e.* 17, 5, 12, 6, 16, 3, 18 m depths) without the operator being aware of the recorded depth of sample. Two techniques were made for each of the three primary parameters: O_2 (Winkler and Hach), dissolved solids (TDS meter and chloride titrations), and temperature (meter and glass thermometer), and each technique was applied by at least two of us. The data are concordant with stratification caused by dissolved solids and discordant with stratification caused by water temperature. The halocline was between 13 and 15 m depth, which approximated the upper edge of the Old Red River Channel at that location and date. To determine if the salt-laden hypolimnion was restricted to the old channel we sampled at Preston Point on 2 July during extremely windy weather, when crest height of waves exceeded 1 m. At that time the halocline there was at about 20 m depth (Figure 3) and restricted the hypolimnion to the Old Red River Channel. These data again are concordant with dissolved solid stratification and discordant with thermal stratification. The extent of the hypolimnion was studied 16 July near the start of an interval with minimal winds (Figure 4). Three downstream stations east of Preston Point showed that stratification involved O_2, temperature, and dissolved solids. Clearly, the hypolimnion had flowed over the edge of the old channel and had covered much of the old flood plain. The hypolimnion pool had risen to near the level of the old channel edge off UOBS. Upstream at

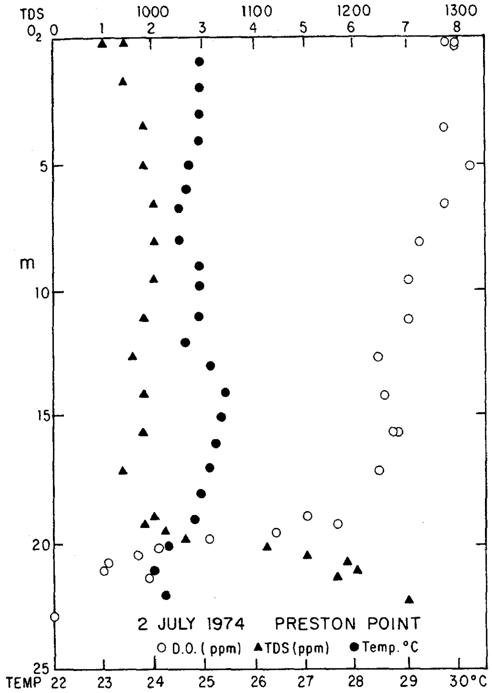

FIGURE 3. Thermal and chemical measurements from Lake Texoma off Preston Point 2 July 1974, an exceedingly windy day.

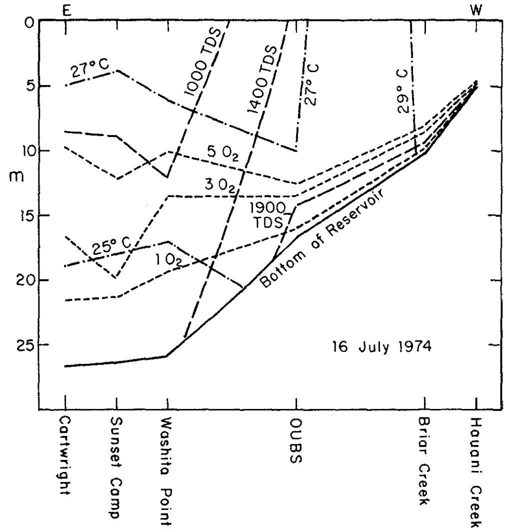

FIGURE 4. Thermal, TDS, and dissolved oxygen (in ppm) profiles in Lake Texoma 16 July 1974. The E.-W. directions are distorted. Note the association of O_2 with TDS to the west and the general concordance of all three to the east.

Hauani Creek (just to the west of the Red River Delta that had nearly filled the reservoir) and Briar Creek stratification did not involve temperature (±<0.2ºC) and oxygen correlated with dissolved solids. This profile shows that salt-laden waters flow under less saline epilimnion waters and that both layers become progressively less saline to the east. If the hypolimnion pool rises east of UOBS in still weather, a continuation should result in the hypolimnion overflowing the channel near UOBS. Subsequent to 12 July that overflow was obvious and (Figure 5) the flood plain was covered with hypolimnion water. After early July our profiles off UOBS could be interpreted to include a thermocline as well as a halocline.

Gill nets set at <5 m and at 9 m always contained more than 0.5 kg/m and 0.5 fish/m per 24 hrs. Those set at > 16 m never exceeded 0.02 kg/m and 0.03 fish/m and after 17 July never had any fish. Nets set at 12.5 m 11-19 July had 0.12 kg/m and 0.37 fish/m (11th); 0.15 kg/m and 0.29 fish/m (12th); 0.13 kg/m and 0.19 fish/m (17th); 0.08 kg/m and 0.25 fish/m (18th); and 0.07 kg/m and 0.03 fish/m (19th). The suspended gill net set at 12.5 m had a similar decline in catch 17 to 19 July. Clearly, the abundance and weight of fish in both 12.5 m nets declined as the hypolimnion rose to cover each net.

The abundance of species seems also to be negatively affected by hypolimnion conditions. Our samples from >16 m had only *Ictalurus* (two individuals), *Dorosoma* (one), *Cyprinus* (one), and *Aplodinotus* (three). Nets set at or near the hypolimnion captured those taxa and numerous *Morone*, *Ictiobus*, and *Carpiodes*. *Aplodinotus* seems to be the fish most tolerant of hypolimnion conditions as most of the fish in the 12.5 m bottom net on 19 July were freshwater drum.

DISCUSSION

Although we know of no previous published record of a halocline as a primary cause for stratification in Lake Texoma one should not be surprised that this occurs. In many ways Lake Texoma is similar to Keystone Reservoir, in which a northern arm (Arkansas vs Washita) has less saline and a southern arm (Cimarron Arm vs Red River) has more saline waters. Eley, *et al*. (5) clearly showed that salinity from the Cimarron Arm is the primary cause for

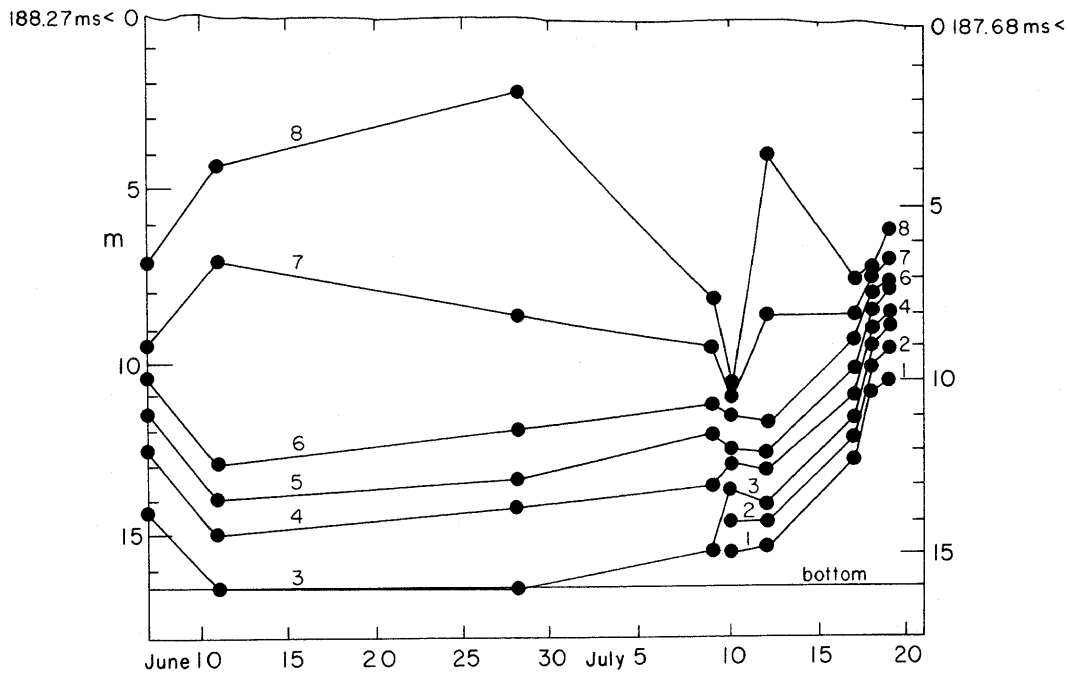

FIGURE 5. Oxygen profiles (in ppm) with time off UOBS. The surface profile reflects changes in Lake Texoma levels (meters above median sea level) during June and July 1974.

stratification. Lake Texoma differs from Keystone primarily in that the salt inflow of the Red River is more dilute than that of the Cimarron Arm so that the halocline seldom separates layers with dissolved solid differences exceeding 0.6 ppt whereas Keystone often has 3 ppt differential. It is not surprising, therefore, that the halocline in Lake Texoma is more restricted to the old channel than is the halocline in Keystone Reservoir.

We feel that stratification in the Red River Arm of Lake Texoma occurs annually in the following manner: high flows typical of spring and winter seasons fill the Red River Arm with water of about 1.0 ppt TDS. As the flows decline in late spring and early summer that inflow water has more dissolved solids [Water Resources Data for Texas for 1969-1972 (6) report that 57% of the recorded Red River flows at Gainesville of more than 60 m^3/sec have less than 1 ppt but those flows less than 10 m^3/sec have more than 2 ppt 90% of the time]. The more saline low-flow waters accumulate at the edge of the delta near Hauani Creek. The eastern edge will sink under the less saline high-flow waters and flow down the old river channel. If the winds are reasonably strong, that saline water which overflows onto the old flood plain is mixed with the epilimnion water by wave-caused currents. We noted that the depth of halocline remained at the edge of the channel (13 m) off UOBS until quiet weather, after which the halocline rose to cover the old flood plain with 3 m of saline water. At the beginning of the overflow on 12 July with a mild south wind, the overflow was at 11.5 m on the north and 12.5 m depth on the south side of the channel, suggesting that the subsurface counter-flow was piling the overflow onto the upwind shore. Current-caused erosion of the hypolimnion would elevate the TDS in the epilimnion, but in turn, tributary inflows would cause decrease of the high TDS at the eastern end of the lake. This is pronounced east of Preston Point where the Washita River inflow would have a major impact. At times the saline hypolimnion from the Red River Arm will flow a distance into the Washita Arm.

Two phases seem to occur in summer: a) an early phase with the hypolimnion flowing down the old river channel and any overflow being mixed into the epilimnion by wind-caused currents. The excess hypolimnion water would leave through the electric generating tubes which are located near the bottom; and b) a later phase when the hypolimnion overflows onto the old flood plain during quiet water.

The first phase would involve a 3-4 m deep, ca 100 m wide mass of water of high TDS. An inflow of 10 m^3/sec would signify a hypolimnion flow rate approximating 0.5 m/min. Nearly one month would be needed for this water to flow the 22 km from Hauani Creek to UOBS. Seasonal warming would be more rapid in the shallow Red River than in Lake Texoma so that the water in the hypolimnion not exposed to solar radiation should be about as warm as the epilimnion waters exposed to seasonal warming at the sampling time. One month is more than sufficient (at 25 C) for depletion of the dissolved oxygen in the saline water flowing down the old river channel. Clearly, epilimnion-dissolved oxygen must be diffused through the halocline to maintain the 3 ppm concentrations noted in late June and the 1 ppm O_2 noted at Preston Point on 2 July (that water is believed to have been in the hypolimnion since early May). The bottom muds have a high O_2 demand; a 1% mud mixture reduced O_2 from 10 ppm to less than 1 ppm in 30 min at 25 C. Under these conditions drum (*Aplodinotus*) and catfishes (*Ictalurus*) are the only fish of which we took more than one individual from the hypolimnion.

The second phase would begin with the first prolonged period of quiet weather. Hypolimnion water would continue to flow down the old river channel and fill the lake bottom initially near Denison Dam (ca 30 m deep) and progressively cover more and more of the bottom. As quiet weather is typically also hot weather, the surface would warm rapidly and a thermocline could form which would reinforce the dissolved solids stratification previously established. The increased mass of hypolimnion water present would signify more time lapse since Red River inflow or a greater difference in seasonal warming. The strong stratification would result in complete oxygen depletion in the hypolimnion. This is in accordance with our gill-netting samples, which produced no fish under these conditions.

It is unfortunate that previous reports do not record the relationship of dissolved solids to oxygen depletion at the bottom of Lake Texoma. Sublette (7) emphasized shallow waters in his discussion of the bottom fauna, and his stations were all in water too shallow to sample hypolimnion formation. Grinstead's (8) white crappie study included a 13± m station but it was not in the old channel. Both Sublette and Grinstead recorded occasional low O_2 readings and thermal stratification at depths similar to those at which we have noted hypolimnion overflow. If we had not recorded dissolved solids and had not sampled from the old river channel, our conclusions would have resembled theirs. Houser (9) sampled from the channel but did not record physico-chemical data. His report of best catches from old brush suggests that most fish were above the channel bank — our gill nets set on the old channel bank were snagged on old brush — and that the old river channel was adversely affected by oxygen depletion in the hypolimnion.

Although one can interpret Grinstead's and Sublette's data to suggest stratification of Lake Texoma, they do not prove long-term hypolimnion formation. In addition to Dr. Robertson's 1970 data we find a) Leifeste *et al*. (10) reported temperature and oxygen stratification on 25-27 July, 1967; their profile on p. 27 shows that specific conductance changed at the same depths as did temperature and dissolved oxygen; and b) Mitchell *et al.* (11) showed oxygen depletion with depth, but seldom was a thermocline formed. As they did not measure dissolved solids they would not be expected to determine the cause for stratification.

The complete depletion of dissolved oxygen in the hypolimnion and the rise of the halocline during hot, quiet weather forces most fishes into the narrowing epilimnion. Hot still weather also stimulates increased use of air conditioners, which in turn increases the demand for hydroelectric generation that further compresses available living space for fishes in the reservoir above the power plant by lowering the lake surface. Although the fish biomass in Lake Texoma may be reduced seasonally, the changes in epilimnion volume would concentrate all fishes in shallows where they would be available for harvest by sport fishermen.

CONCLUSION

Lake Texoma stratified in 1974 with concentrations of dissolved solids being the primary cause. Windy weather restricted the hypolimnion to the Old Red River Channel, where dissolved O_2 was between 2 and 3 ppm. Quiet weather permitted greater separation of epilimnion and hypolimnion waters, a rise in the halocline, elimination of dissolved O_2 at the bottom, and establishment of a thermocline that coincided with the halocline. Reduction of dissolved oxygen restricted most fishes to waters less than 10 m deep.

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REFERENCES

1. R. A. RYDER, S. R. KERR, K. H. LOFTUS, and H. A. REGIER, J. Fish. Res. Board Can. 31: 663-88 (1974).
2. R. M. JENKINS and D. I. MORAIS, in G. E. Hall (ed.), *Reservoir Fisheries and Limnology*, American Fisheries Society, Washington, 1971, p. 371-84.
3. F. RUTTNER, *Fundamentals of Limnology*, University of Toronto Press, Toronto, 1963.
4. M. J. TARAS, A. E. GREENBERG, R. D. HOAK, and M. D. RAND (eds.), *Standard Methods for the Examination of Water and Waste Water,* 13th ed., A.P.H.A. — A.W.W.A. — W.P.C.F., Washington, D.C., 1971.
5. R. L. ELEY, N. E. CARTER, and T. C. DORRIS, in *Reservoir Fishery Resources Symposium,* American Fisheries Society, Washington, 1967, p. 333-57.
6. United States Geological Survey. *Water Resources Data for Texas.* Part 2. *Water Quality Records*, 1969-1972.
7. J. E. SUBLETTE, Texas J. Sci. 7: 164-82 (1955).
8. B. G. GRINSTEAD, Okla. Fish. Res. Lab. Bull. 3, 1969.
9. A. HOUSER, Okla. Fish. Res. Lab. Rep. 63, 1957.
10. D. K. LEIFESTE, J. F. BLAKEY, and L. S. HUGHES, Texas Water Dev. Bd. Rept. 129.
11. R. P. MITCHELL, F. S. CARL-MITCHELL, and G. H. WARD, Espey, Huston, and Associates Doc. 7401.