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The Occurrence of Fish Remains in Modern Lake Systems : A Test of the Stratified-Lake Mode

Douglas R. Britton

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Abstract

The Occurrence of Fish Remains in Modern Lake Systems: A Test of the Stratified-lake Model

by

Douglas R. Britton

Theories regarding the taphonomy of fishes in lacustrine environments have traditionally relied on an anoxic water column to explain the excellent preservation. This concept has never been directly tested in modern lacustrine environments that are thought to be analogous to the lacustrine environments predicted by the Stratified-lake Model. This research tested that model by searching for fish remains in 38 collected bottom samples of six modern lacustrine analogues, including Fayetteville Green Lake, New York. The bottom sediments of a warm, holomictic, shallow, and saline lake (Salton Sea, California) were also examined. Although laminated sediments were found in all of the lakes studied, only the Salton Sea sediments contained fish remains. This was surprising in that one would have expected the opposite: abundant fish remains in the stratified lakes and few, if any in the non-stratified, saline lake.

In addition to the above described study, a preliminary study of the taphonomic processes effecting fish carcasses was carried out at Lake Perris, CA. Fresh fish carcasses

were lowered in buckets to the bottom of the lake in both the epilimnion (water temperature >15 deg. C. and oxygenated) as well as the hypolimnion (water temperature <15 deg. C. and anoxic), directly testing the effects of oxygen content, temperature, and pressure on the preservation of fishes. In the warm, oxygenated water decomposition took place, producing enough gasses in the fish bodies to cause them to float to the surface. In the cool, anoxic environment, decomposition of the fleshy parts was initiated, but not enough gasses were produced to cause the fish to float to the surface. Further study is needed to better understand the separate effects of oxygen content, temperature, and pressure on the taphonomy of fishes.

The results of this research strongly suggest that anoxia alone is not adequate to preserve fish remains and that some other physical, chemical, and/or biological condition may be necessary for the preservation of fishes. The results obtained at Salton Sea suggests that saline, alkaline lake waters may be important in the taphonomic process. Further studies in these environments should be productive.

LOMA LINDA UNIVERSITY

Graduate School

THE OCCURRENCE OF FISH REMAINS IN MODERN LAKE SYSTEMS:
A TEST OF THE STRATIFIED-LAKE MODEL

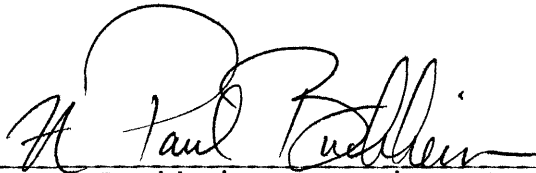
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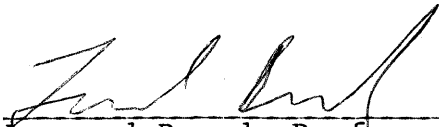
A Thesis in Partial Fulfillment
of the Requirements for the Degree Master of Science
in Geology

June 1988

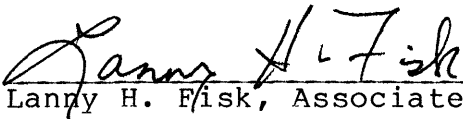
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Earl Lathrop, Professor of Biology

ACKNOWLEDGEMENTS

I am indebted to Dr. H. Paul Buchheim for his guidance and contagious enthusiasm for this project. I thank Depak Plaha, who gave me indispensable assistance and company during the weeks of field work. I also thank Gary Faulkoner of the California Department of Water Resources for providing me with the water column profiles of Lake Perris. I thank the California Parks and Recreation for providing me easy access to Lake Perris. Finally, for financial assistance I thank Geoscience Research Institute.

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INTRODUCTION

Taphonomic conditions postulated for the preservation of fishes in lacustrine environments relies heavily on the concept of a stratified lake (Stratified-lake Model) with an anoxic hypolimnia (Bradley, 1948, 1963; McGrew, 1975; Shafer, 1972; Smith and Elder, 1985; Wilson, 1977). These conditions are also regarded necessary for the preservation of finely laminated oil shale in lacustrine environments (Anderson and Dean, 1988; Boyer, 1981; Bradley, 1929, 1973; Dean and Fouch, 1983; Ludlam, 1976). It was the objective of this study to specifically test the concept that under anoxic conditions fishes will be preserved. Specific objectives were to document the presence or absence of fish remains in modern lacustrine environments whose conditions have been used as analogues for the Stratified-lake Model, as well as to document if sediments are being deposited and preserved as thin organic rich laminae in anoxic and/or oxic water conditions.

There is significant controversy regarding the preservation of fishes in laminated lacustrine sediments. The concept of an anoxic hypolimnion is regarded necessary for the preservation of the laminated sediments and fishes because these bottom conditions are hostile to benthic and burrowing organisms that would otherwise disrupt preservation of the laminae and fishes. The anoxic

environment allows fish carcasses to remain on the bottom without being disturbed by bottom scavengers and decomposition, thus preserving the fish through later burial. Will anoxic conditions preserve fish carcasses in modern lakes, whose conditions are used as modern analogues to the Stratified-lake Model, or are some other parameters necessary? Elder and Smith (1988) reported that anoxic conditions do not prevent decomposition but may prevent scavenging. Shafer (1972) experimented with decomposition of fish carcasses and has shown that in an oxic environment fishes will decompose; filling with gases and floating to the surface, resulting in the disarticulation of the fish and subsequent scattering of the fish remains around the lake. The floating and resulting disarticulation of the fish indicates that an anoxic environment is necessary to preclude decomposition and allow subsequent slow burial. However, recent work has suggested that a stratified lake with an anoxic hypolimnion may not be necessary for the preservation of fishes (Buchheim and Eugster, 1986; Buchheim and Surdam, 1977, 1981). Also Breder (1957) observed that in some aquariums fishes were preserved for several months in an oxic environment after death. Buchheim and Surdam (1977) argued that the presence of preserved articulated catfish and abundant fish coprolites in finely laminated oil shale indicate that the catfish were a resident population and therefore indicating an oxic environment. Boyer (1982)

disagreed and argued that the catfish were transported into the anoxic hypolimnion after death and were subsequently preserved intact. Shafer (1972) has shown, in laboratory experiments with different species of fish, that transport of a fish shortly after death results in disarticulation of the fish.

The purpose of this study was to document the presence or absence of fish remains in the bottom sediments of environments postulated as modern analogues to the Stratified-lake Model. It was also my purpose to observe the effects that oxic and anoxic conditions have on the decomposition of fishes.

METHODS

The bottom sediments of seven modern lakes were studied in an effort to determine the taphonomic fate of fish carcasses. Five lakes listed in the literature (Anderson, et al., 1985) as stratified with anoxic hypolimnia and with laminated sediments, and one not listed, were chosen for study (Figure 1). The bottom sediments in the oxygenated zone of some of the above lakes were also sampled as controls. One saline lake with laminated sediments and an oxygenated water column was also studied. In addition, a preliminary fish taphonomy experiment was conducted (see Appendix A for results and discussion).

Specific methods included the following:

1. Water samples were collected using a deep water sampler and analyzed for oxygen concentrations, temperature, and pH. Water samples were taken approximately 3 - 5 centimeters from the surface and approximately one half meter above the bottom. Water temperature was measured at one meter intervals throughout the water column to establish the depth of the thermocline. It was assumed that the thermocline is also the depth of the chemocline. An oxygen meter and probe provided dissolved oxygen concentrations, and a pH meter provided pH. Oxygen concentrations, pH, and



1. Salton Sea, California
2. Squaw Lake, Minnesota
3. Elk Lake, Minnesota
4. Dark Lake, Wisconsin
5. Little Pine Lake, Wisconsin
6. Hassler Lake, Michigan
7. Fayetteville Green Lake, New York

Figure 1. Map showing location of lakes studied.

- temperature were measured on the boat immediately after taking the water sample.
2. Six to ten bottom sediment samples were collected at each lake. An Eckman dredge (maximum possible sample volume of 12,167 cm³.) was used to obtain the sediment samples. The dredge could penetrate down to a depth of 23 centimeters depending upon the consolidation of the bottom sediments. A general description of the sediment sample was recorded immediately upon collection, with particular emphasis on the nature of bedding (e.g. laminated vs. massive). Before sieving, a "core" of each sediment sample was taken using four inch diameter polyvinyl chloride (pvc) pipe. The pvc pipe was capped and the sediment core was returned to the lab for further study. This method of "coring" was very effective in preserving sedimentary structures. Approximately 50% of each bottom sediment sample was sieved immediately upon recovery using a standard sediment sieve with a mesh size of one millimeter. Any material retained in the sieve was identified and the relative percentages recorded. The percentage of total sieve residue vs. total sample volume was calculated.
 3. Bottom sample locations were determined by using a coordinate system with headings sighted on prominent features along the shoreline and plotted on a map of the lake.

4. The methods and results of experiments directly testing the effects of different water column conditions (oxygen concentrations, temperature, pressure) on the decomposition of fish are discussed in Appendix A.

RESULTS

Surprisingly no fish remains were found in any of the stratified freshwater lakes studied as would have been predicted by the Stratified-lake Model. The only lake containing any fish remains was Salton Sea. This lake is shallow, oxygenated to the bottom, saline, and warm (water temp > 15 deg. C.). Disarticulated fish remains were found throughout the laminated bottom sediments. Abundant disarticulated fish remains were also found in storm lag deposits along the shore.

The following are brief descriptions of each lake studied with a description of a typical sieve sample residue. See Figure 2 for the dredge sample locations for each lake. Refer to Table 1 for a compilation of sieve residue results for each lake. Table 2 displays complete water column characteristics for each lake. Appendix B gives a more detailed description of the sediment sample and sieve residue from each lake sample location. The Lake Perris fish preservation experiments are discussed in Appendix A.

Salton Sea, California

Salton Sea (abbreviated SS) lies 380 meters below sea level and is located in southern Riverside County and

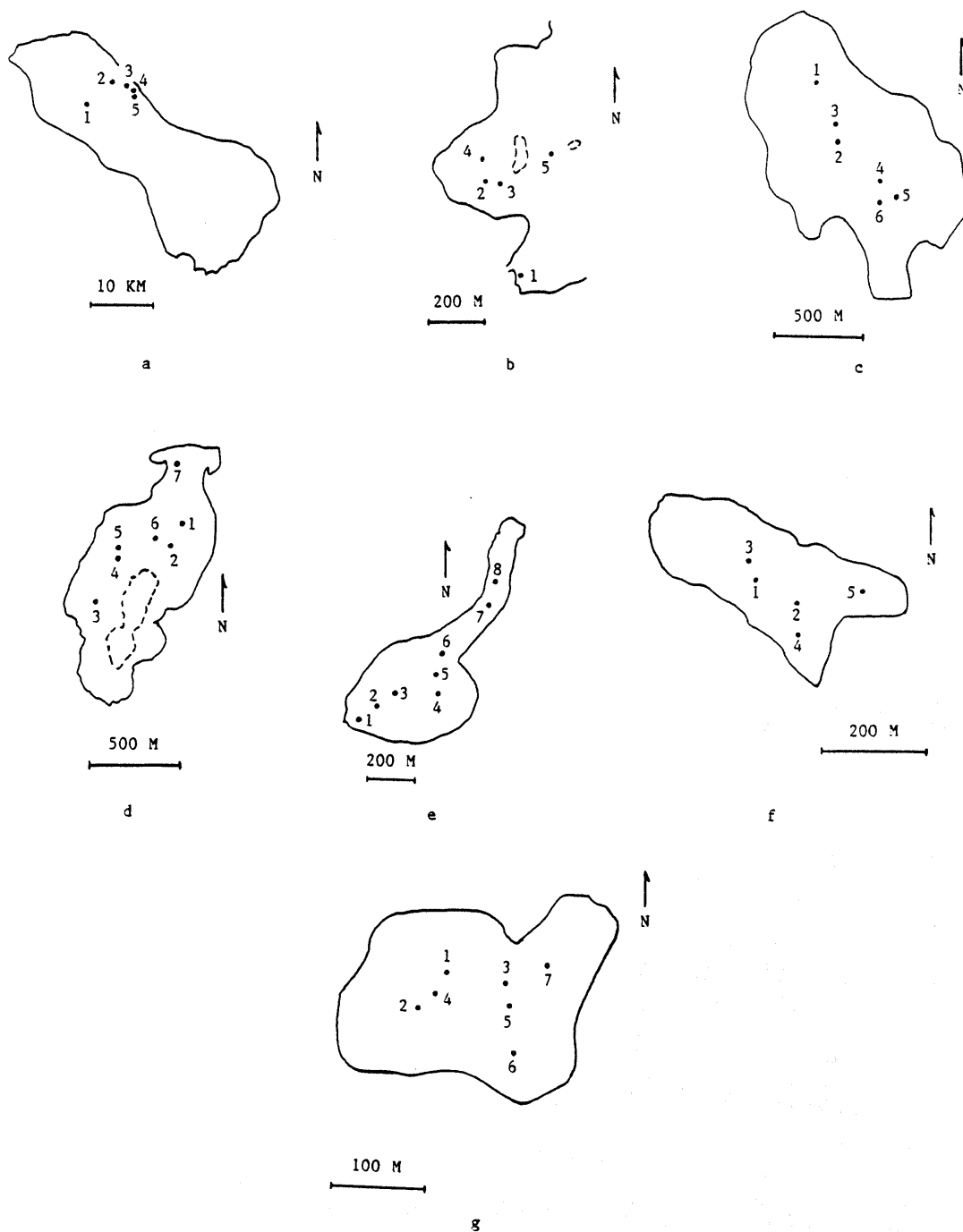


Figure 2. General outline of each lake, showing sampling sites. a) Salton Sea, California, b) Hassler Lake, Michigan, c) Elk Lake, Minnesota, d) Squaw Lake, Minnesota, e) Fayetteville Green Lake, New York, f) Dark lake, Wisconsin, g) Little Pine Lake, Wisconsin. Dashed lines represent outline of islands.

	SS	HL	EL	SL	FGL	DL	LPL
SURFACE							
Temp. (deg. C)	21.0	22.0	22.0	23.0	20.0	25.0	29.0
Oxygen (ml/L)	9.6	7.3	8.5	8.9	8.1	7.6	6.6
pH	6.6	7.2	7.3	N/A	6.6	7.8	8.2
BOTTOM							
Temp. (deg. C)	20.0	10.0	6.0	7.0	8.0	5.0	5.0
Oxygen (ml/L)	2.6	.0	1.4	1.3	.0	.8	1.2
pH	6.6	7.1	6.8	N/A	6.8	8.1	7.6
Depth of measurement (m)	11.7	7.0	24.0	21.0	51.0	18.0	18.3

Table 1. Summary of water column characteristics for each lake. Surface samples collected approximately 3 - 5 cm. below water surface; bottom samples collected approximately 0.5 m. above lake bottom. SS = Salton Sea, HL = Hassler Lake, EL = Elk Lake, SL = Squaw Lake, FGL = Fayetteville Green Lake, DL = Dark Lake, LPL = Little Pine Lake. N/A = not available. Salton Sea is a saline lake with a salinity of approximately 33 ppt.

	SS	HL	EL	SL	FGL	DL	LPL
Bottom oxygen (ml/L)	2.6	.0	1.4	1.3	.0	.8	1.2
Laminated sedments	P	P	P	P	P	P'	P
Typical % sieve residue of total sample	2-3%	3-5%	1-2%	10%	3-5%	2-3%	3-5%
Plant debris	T	A	A	A	A	A	A
Mollusc shells	C	C	C	T	C	AB	AB
Insect remains	AB	AB	AB	AB	AB	T	AB
Annelids	AB	AB	T	AB	AB	T	AB
Fish remains	A,C	AB	AB	AB	AB	AB	AB

Table 2. Summary of data collected at each lake. A = abundant (60 - 100% of total sieve residue), C = common (2 - 60% of total sieve residue), T = trace (<2% of sieve residue), AB = absent, P = present, P' = presence not observed but is recorded in literature. SS = Salton Sea, HL = Hassler Lake, EL = Elk Lake, SL = Squaw Lake, FGL = Fayetteville Green Lake, DL = Dark Lake, LPL = Little Pine Lake. Plant debris includes leaves, twigs, bark, moss, and seeds. Fish remains consist of scales, bones, and fleshy parts. Each lake supports a fish population.

northern Imperial County approximately 33 kilometers southeast of Indio, CA on highway 111. The lake covers approximately 1000 square kilometers with a maximum depth of 13.8 meters and an average depth of 3 - 6 meters. The origin of Salton Sea is traced to early 1905, when for two years the Colorado River was accidentally diverted through irrigation canals into the Salton Basin. The basin was filled to a depth of 24.1 meters and covered an area of 1430 square kilometers. Since then the lake level has stabilized and is in equilibrium with inflow and evaporation. Salton Sea is surrounded by a desert environment that is heavily irrigated and farmed, resulting in sufficient irrigation runoff to maintain the lake level.

The lake is a popular fishing spot, supporting large populations of fish species similar to the types found in the Gulf of California. It is common to find many fish carcasses along the shoreline and floating in the water. Local residents attribute the mass mortalities of the species of fish to rapid increase in water temperature.

Salton Sea differs from the other lakes that were studied as part of this thesis research in that it is a saline lake with a salinity of about 33 ppt. Water column characteristics are summarized in Table 1. Water temperature varies little throughout the water column. At the time of this study, late November 1986, water temperature was measured as 21.0 deg. C. at the surface and

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20.0 deg. C at a depth of 11.7 m. Carpelan (1958) plotted mean water temperature versus mean air temperature over a two year period, and showed that water temperatures very closely follow air temperatures.

It is also important to notice that this lake is not meromictic or stratified. Oxygen concentrations did reduce as depth increased but at the time of this study the oxygen concentrations of the bottom waters were 2.6 ml/L, sufficient to support fish life. Carpelan (1958) did report that for very short periods of time the lake became stratified with an anoxic hypolimnion. This occurred several times in the summer and only during periods of the day when there was no wind to create currents that would mix the water column.

The bottom sample from location #2 (Figure 2a) is a typical sediment sample. The dark H₂S-rich clay was thinly laminated (1 - 3 mm.) in the top 10 cm. The sieve residue constituted approximately 2 - 3% of the total sediment sample volume. The sieve residue was composed of 30 - 35 % fish remains, 2% plant material, and 60% broken pieces of small barnacles. The fish remains found in the sieved residue were disarticulated, consisting of scales, vertebrae, other bones, and operculae.

Hassler Lake, Michigan

Hassler Lake (abbreviated HL), a fresh water lake covering an area of approximately 0.70 square kilometers, is located in Genesee County near Flint, Michigan. The lake is protected from winds by the surrounding low woodlands. Lake productivity is facilitated by a swamp half the size of the lake located along the southern lake margin. Maximum lake depths of approximately 15 - 18 meters occur nearest the two western islands. Stream inflow maintains the lake's level.

The lake is reported to be a very good fishing locality, but only to a depth of about 6 meters (the depth of the pycnocline). Local residents report populations of bass, pike, bluegill, and crappie.

The water temperatures measured show a 12 deg. C. difference between the surface and bottom. See Table 1 for a summary of water characteristics. Oxygen concentrations of 0.0 ml/L on the bottom demonstrate anoxic conditions at the time of this study.

The bottom sample from location #3 (see Figure 2b) is typical and is composed of dark gray to black H₂S-rich, poorly laminated clay. The sieve residue, containing only plant material, constituted approximately 3 - 5% of the total sample volume.

Elk Lake, Minnesota

Elk Lake (abbreviated EL) is a temperate fresh water lake located approximately 7 kilometers south of Lake Itasca in Itasca State Park, Clearwater County, northwestern Minnesota. The lake covers an area of 0.10 square kilometers with an maximum depth of about 30 meters. Although this study observed no laminae in the bottom sediments, Anderson et al. (1985) and Anderson and Dean (1988) reported the presence of "varves". Dean et al. (1984) also reported that "varves" were forming in Elk Lake. The lake is protected from blowing winds by woodlands that completely encompass the lake. Oxygen concentration of 1.4 ml/L exist at the bottom and up to a depth of about 21 meters (it is assumed here that the depth of the thermocline is the minimum depth of low oxygen concentrations).

The lake is a popular fishing locality for park visitors and local residents. Fish diversity in the lake is large; local fishermen report minnows, shiners, bass, pike, sunfish, bluegill, crappie, and some bullhead catfish.

Bottom sample #5 (Figure 2c) is typical and is composed of dark black H₂S-rich clay with some 5 mm. thick laminae. The sieve residue constituted approximately 1 - 2% of the sample volume and consisted of 70% plant material, 30% live annelids, and <1% that appeared to be calcified burrows roughly 1 - 3 cm. in length. No fish remains were found.

Squaw Lake, Minnesota

Squaw Lake (abbreviated SL), a temperate fresh water lake is located approximately 4 kilometers west-southwest of Lake Itasca in Itasca State Park, Clearwater County, northwestern Minnesota. It covers an area of approximately 0.61 square kilometers with a maximum depth of about 24 meters.

This lake is also protected from winds by surrounding woodlands. A stream supplies inflow from the south and the lake drains out to the north. Measured oxygen concentrations of 1.3 ml/L show the lake to have low oxygen from bottom to a depth of approximately 12 meters (the depth of the thermocline).

This lake is heavily fished by park visitors and local residents. The types of fish present are similar to Elk Lake, but there are no catfish reported in this lake.

Sample #5 (Figure 2d) is typical and is composed of black H₂S-rich laminated clay. The sieve residue constituted approximately 10% of the total sample volume and consisted of almost 100% plant material with <1% live annelids. No fish remains were found.

Fayetteville Green Lake, New York

Fayetteville Green Lake (abbreviated FGL) is a temperate fresh water lake located in Green Lakes State Park, Onondaga County, approximately 3.3 kilometers northeast of Fayetteville, New York. It covers an area of 0.26 square kilometers with a maximum depth of about 54 meters. The lake has very steep sides (maximum slope of about 55 deg.). This gives the lake a very small surface area to depth ratio which is important in maintaining meromixis. The lake is reported to be permanently meromictic (Anderson et al., 1985) with a chemocline at approximately 18 meters. Brunskill and Ludlam (1969) concluded that the permanent stratification of the lake was partially the result of a slightly higher total dissolved solids in the monimolimnion.

The lake is surrounded by wooded rolling hills which protect the lake in its natural basin from winds. The lake is one in a series of two plunge basins created by glacial waterfalls during deglaciation (Miner, 1933 and Coon, 1960). The lake has been scoured out of shale and dolomite formations. The soil surrounding the lake consists of interspersed glacial till and gravel beds. The lake's unique aqua water color is due to a high concentration of suspended carbonate. The bottom sediments of the lake have been extensively studied, and are interpreted as "varve" and

density current deposits (Ludlam, 1969). Flat lying sediments below 20 meters are thinly bedded (Brunskill and Ludlam, 1969 and Ludlam, 1969).

Oxygen concentrations measured during this study confirm its stratification, with anoxic conditions below a depth of about 18 meters. Table 1 summarizes the water column characteristics.

The lake is heavily fished by local residents and park visitors. The lake is stocked yearly with trout and salmon. There are also resident populations of crappie and bluegill which can be seen in the shallows along the shoreline.

The sediment sample from location #3 (Figure 2e) is typical, consisting of dark gray to black H_2S -rich 3 - 4 mm. thick laminated clay. The sieve residue constituted approximately 3 - 5% of the sample volume and consisted of 95 - 98% plant material with some gastropod shells and small (1 mm.) spherical calcite crystals. No fish remains were found. Vallentyne (1960) also sampled the bottom sediments of Fayetteville Green Lake and also reported the absence of fish remains.

Dark Lake, Wisconsin

Dark Lake (abbreviated DL) is a temperate fresh water lake located in Chippewa County, Wisconsin about 30 kilometers north of Chippewa Falls off of Highway 40. It

covers an area of approximately 0.052 square kilometers with a maximum depth of 18.6 meters.

The lake is protected from winds by surrounding wooded hills. A swamp borders the northwest shoreline. Anderson et al. (1985) reported that the bottom sediments were laminated.

The local residents describe the lake as a good trout fishing locality, and I also noted resident populations of crappie and bluegill. A few years prior to this study the Department of Fish and Game poisoned the fish in an effort to kill the population of pike. The lake has subsequently been stocked yearly with trout.

Measured oxygen concentration of the bottom waters indicate only a small amount, 0.8 ml/L., of oxygen present (Table 1). The lake shows strong temperature stratification with a 20 deg. C. difference within the water column from surface to bottom.

Sample #3 (see Figure 2f) is typical, composed of dark brown H₂S-rich clay constituting 2 - 3% of the total sample volume and consisted of 100% plant material. No fish remains were found.

Little Pine Lake, Wisconsin

Little Pine Lake (abbreviated LPL) is a temperate fresh water lake located within 100 meters of Dark Lake in

Chippewa County, Wisconsin. The lake covers an area of 0.4 square kilometers with a maximum depth of 18 meters.

The lake is surrounded by woodlands which protect its limited surface area from winds. The lake is heavily fished by local residents and is reported to be stocked yearly with trout. I also noted populations of crappie and bluegill.

Water samples indicated an oxygen concentration of 1.2 ml/L near the bottom, and a well developed thermocline at depth between seven and nine meters. Anderson et al. (1985) reports laminated bottom sediments in the lake.

Sediment sample from location #4 (Figure 2g) is typical, composed of dark green to black H₂S-rich laminated clay. The sieve residue, constituting 3 - 5% of the total sample volume and consisted of 100% plant material. No fish remains were found.

DISCUSSION

Study of the water column characteristics and organic remains in the bottom sediments of modern analogues does NOT support the taphonomic concept that an anoxic hypolimnion of a stratified lake is adequate to explain fish preservation in ancient lake systems. Traditional theories regarding the preservation of fishes in ancient lake environments dictate that one should find fish remains in modern analogues of the ancient environments. The fact that no fish remains were found in either Fayetteville Green Lake or Hassler lake, two stratified lakes with anoxic hypolimnion, suggests that an anoxic hypolimnion of a stratified lake in itself is not responsible for the preservation of fish remains.

If we assume for a moment that at least one fish dies per year per 10 M² scattering (conservatively) 200 bones and at least 1000 scales, then we would expect to find approximately 200 bones and 1000 scales in 10 M² of bottom area per year if preservation was occurring. In Fayetteville Green Lake it is estimated (Ludlam, 1969) that approximately one centimeter of sediment is deposited approximately every 10 years. Our 23 cm. deep sediment sample represents 230 years of deposition and should include 46,000 bones and 230,000 scales in the 10 M² area; or 4,600 bones and 23,000 scales per square meter; or approximately 288 bones and 1438 scales per 529 cm.², the area covered by

an Eckman dredge; therefore we should have found some evidence of preservation of fishes in our sampling of the bottom sediments. What then has happened to the fish remains? We can only conjecture as to the taphonomic fate of the fish. Perhaps no fish carcasses or parts ever reached the bottom. It may be that decomposition (including gas build up) took place before the carcasses ever had a chance to reach the bottom, or shortly after reaching the bottom, causing the fish to float to the surface and subsequently be washed onto the shore by wind and wave action. Alternatively it may be possible that the carcasses completely decomposed, bones and all, without leaving a trace. Or it may be that the fish live mainly around the edges of the lake in the oxygenated zone. After death they decompose and are never transported to the anoxic environment, unlike some assume (Boyer, 1982). It may also be possible that the fish are completely removed each year by fishing and predation, although normal mortality rates should result in some record within the sediment.

If an anoxic hypolimnion does not explain fish preservation, then some other physical, biological, and/or chemical constraints must be responsible for the preservation of fishes in ancient lake systems. There are several possibilities:

The results from Salton Sea suggest that salinity and alkalinity may play an important role in fish preservation.

This lake is shallow, warm, and oxygenated to the bottom and yet abundant disarticulated fish remains were found in the bottom laminated sediments. Articulated carcasses and extremely abundant fish bones were observed in storm lag deposits along the shore. The abundance of fish remains reflects the preservation potential of fishes in this lake and/or the mass mortalities of fishes that commonly occur here.

Elder and Smith (1988) suggested that temperature plays a significant role in preservation. Their laboratory experiments with the decomposition of fish in anoxic environments has shown that anoxia in itself will not preclude decomposition. Experiments conducted at Lake Perris (Appendix A) in a low temperature (approximately 15 deg. C.) and anoxic environment shows that decomposition of the soft tissue does take place in this environment. However, during the time the experiments were conducted, gasses did not develop enough to cause the carcasses to float. It is possible that temperature and not anoxia was the determining factor in preventing flotation. Decomposition of the fish carcasses resulting in flotation did occur in experiments conducted in warm (>15 deg. C.) oxygenated water. Further study is needed to isolate the effects of temperature, pressure, and anoxia.

It may be possible that the type of bacteria present in the water column as well as the type within the fish body is

responsible for either preservation or decomposition. It is assumed that anaerobic bacteria are responsible for decomposition of the carcasses in anoxic environments.

Alkalinity and salinity may have an influence on the taphonomic process. Further studies are planned to test the role of these factors in the preservation of fishes.

This study suggests that under normal circumstances, at least within the stratified-lake systems studied, articulated fish are not being preserved in the large numbers observed in ancient lake systems. Conceivably a combination of all or some of the above conditions discussed above are responsible for the perfect preservation of fishes seen in many ancient lacustrine deposits.

Theories regarding the preservation of thinly bedded lacustrine sediments also rely on anoxic and stratified water column conditions; to prevent bioturbation of the laminae by benthic organisms and rely on meromixis to prevent the disturbance of bottom sediments from water currents created during normal mixing of the lake's water column. Dean et al. (1984) discussed present varve formation in a deep hole of Elk Lake, Minnesota where oxygen levels are measurable, but not high enough to support benthic organisms. The water column conditions at Salton Sea are sufficient to support benthic organisms, yet the bottom sediments are laminated. Further study is necessary to examine the extent and depositional origin of the laminae

preserved in Salton Sea.

CONCLUSION

Based on the evidence presented in this study it can be concluded that an anoxic hypolimnion alone is not adequate to preserve fish remains. It may be that a combination of biological, physical, and chemical conditions are responsible for their preservation. Because most scientists have assumed that anoxia in stratified water bodies is more than sufficient to preserve fishes, no effort has been made to look further. This in turn has very probably resulted in erroneous conclusions about the depositional environment of laminated sediments as well. Further taphonomic and sedimentologic studies that consider other possibilities may open large doors to significant discoveries and cause major revisions to current theories regarding the taphonomy of fishes and the deposition and preservation of laminated rocks.

APPENDIX A

Preliminary studies testing the effects of oxic and anoxic conditions on the decomposition of fishes were conducted in Lake Perris, located in Riverside County near Perris, California. It is a man-made fresh water reservoir maintained by the California Department of Parks and Recreation and the Department of Water Resources. It has a maximum water depth of about 33 meters in a dredged trench near the water outlet tower on the south-west corner of the dam. The lake stratifies during summer months and turns over in early winter. The experiments conducted at Lake Perris were located at various depths near the outlet tower and consisted of the following methods:

1. Channel catfish carcasses were placed in five gallon buckets and lowered into the lake. Ten buckets with wire mesh lids and one catfish in each were placed at a depth of 8 meters. The condition of the fishes were observed by SCUBA three weeks later. Four of these buckets were left for another three weeks for later observation. Two buckets with a catfish carcass in each were left at 8 meters for three weeks without lids to allow the taphonomic process to take its natural course (bucket lids prevented possible flotation of carcasses in previous experiments).

2. One bucket without a lid and with two catfish carcasses was lowered by rope to a depth of 18 meters and into an anoxic and hydrogen sulfide-rich environment. The bucket was left in place for three weeks and then brought to the surface for inspection. Two buckets without lids and containing a total of five catfish were placed at a depth of 23 meters. The buckets were brought up after three weeks and condition of the fishes observed.

3. Water chemistry data of the lake were provided by the California Department of Water Resources. Water column profiles were taken once a week allowing close monitoring of dissolved oxygen, temperature, total dissolved solids, and pH.

The first experiment, consisting of placing 10 buckets in oxygenated (oxygen concentration = 7.5 ml/L, water temperature = 19.5 deg. C.) water at a depth of 8 meters, demonstrated the effects of decomposition of fish carcasses in a shallow, warm environment. The carcasses easily disarticulated with any movement. The second experiment, repeating the first but allowing the fish to float out of the buckets if enough gas was developed, resulted in flotation of the fish carcasses within four weeks.

Experiments conducted in the anoxic environment (water temperature approximately = 15.0 deg. C., depth = 18 m.) revealed similar results. However the fish remained in the

buckets (decomposition not producing enough gas to float the fish) but disarticulated easily upon disturbance. The condition of the fish carcasses was similar to the condition of the carcasses resulting from experiment one.

Further studies which involve repeating the experiments at depths and temperatures similar to the anoxic environment experiments but in an oxygenated environment will single out the effects of pressure and temperature on the decomposition of the fish carcasses.

These experiments have demonstrated that fish carcasses will decompose in anoxic environments. However the process may not produce enough gasses (at least within the period of time the experiment was in progress) to float the fish as it does in a more shallow, warm environment.

APPENDIX B

The following are detailed descriptions of each dredge sample and sieve residue for each lake. Sample locations for each lake are shown in Figure 2.

Salton Sea, California

<u>SAMPLE</u>	<u>DESCRIPTION</u>
1	Clay, dark gray to black, upper 2-3 cm. finely laminated with a strong H ₂ S smell; sieve sample residue composes 2-3% of total sieve sediment sample and consists of 35-40% fish remains, 55-60% broken barnacles, and 2% plant material; sample collected at a depth of 11 m.
2	Clay, gray to black, H ₂ S rich with a 0.5 cm. bed of poorly laminated reddish brown clay at top; sieve sample residue composes 2-3% of total sieve sediment sample and consists of 30-35% fish remains, 60% broken barnacles, and 2% plant material; sample collected at a depth of 13 m.
3	Clay, gray to black, H ₂ S rich with a 0.5 cm. bed of finely laminated reddish brown clay on top; sieve sample composes 2-3% of total sieve sediment sample and consists of 90-95% broken barnacles, 5-7% fish remains, and <1% gastropod shells; sample collected at a depth of 9 m.
4	Clay, gray to black, H ₂ S rich, with coarse to very coarse sands diluting the clays; sieve residue composes 2-3% of total sieve sediment sample and consists of 60% broken barnacles, 30-35% gastropod shells, and 5-10% fish remains; sample collected at a depth of 4.5 m.

- 5 Clay, gray to black clay, H₂S rich and well laminated; sieved data not available; sample collected at a depth of 3.5 m.

Hassler Lake, Michigan

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, dark gray to black, H ₂ S-rich; sieve residue composes 10-15% of total sieve sediment sample and consists of 90-95% plant material, 2-3% gastropod shells, and <1% pelecypod shells; sample collected at a depth of 3 m.
2	Clay, dark gray to black, H ₂ S rich and poorly laminated; sieve residue composes 2-3% of total sieve sediment sample and consists of 95-100% plant material and <1% gastropod shells; sample collected at a depth of 8.2 m.
3	Clay, dark gray to black, H ₂ S-rich; sieve sample composes 3-5% of total sieve sediment sample and consists of 95-100% plant material and <1% gastropod shells; sample collected at a depth of 6.7 m.
4	Clay, dark gray to black, H ₂ S-rich; sieve residue composes 2-3% of total sieve sediment sample and consists of 60-70% plant material and 30-35% gastropod shells; sample collected at a depth of 9.1 m.
5	Clay, dark gray to black, H ₂ S-rich; sieve residue composes 2-3% of total sieve sediment sample and consists of 80-90% plant material, 10-15% gastropod shells, and <1% pelecypod shells; sample collected at a depth of 7.3 m.

Elk Lake, Minnesota

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, black, H ₂ S-rich with an interbed of gray clay; sieve residue composes 2-3% of total sieve sediment sample and consists of 70% plant material and 30% annelids; sample collected at a depth of 12.8 m.
2	Same as sample 1. Sample collected at a depth of 14.0 m.
3	Clay, black, H ₂ S-rich; sieve residue composes 1-2% of total sieve sediment sample and consists of 95% plant material and 2-3% annelids; sample collected at a depth of 20.6 m.
4	Clay, black, H ₂ S-rich; sieve residue composes 1-2% of total sieve sediment sample and consists of 40-45% plant material, 30% annelids, and 25-30% <3cm. solidified (annelid?) tubes; sample collected at a depth of 28.8 m.
5	Clay, black, H ₂ S-rich, poorly laminated; sieve residue composes 1-2% of total sieve sediment sample and consists of 45-50% plant material, 30% annelids, 20% (annelid?) tubes, and 2% gastropod shells; sample collected at a depth of 25.9 m.
6	Clay, black, H ₂ S-rich; sieve residue composes 1-2% of total sieve sediment sample and consists of 90% plant material, 5-10% (annelid?) tubes, and 3% gastropod shells; sample collected at a depth of 26.0 m.

Squaw Lake, Minnesota

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, black; sieve residue composes 7-10% of total sieve sediment sample and

- consists of 100% plant material and 1% annelids; sample collected at a depth of 22.9 m.
- 2 Clay, dark brown; sieve residue composes 5-7% of total sieve sediment sample and consists of 80-90% plant material, 3-5% annelids, 3% (annelid?) tubes, <1% insect remains, and <1% gastropod shells; sample collected at a depth of 11.6 m.
- 3 Clay, dark brown; sieve residue composes 10-15% of total sieve sediment sample and consists of 95% plant material and 3-5% annelids; sample collected at a depth of 17.0 m.
- 4 Same as sample 3 but sieve residue composes 5-7% of total sieve sediment sample and also consists of <1% insect remains; sample collected at a depth of 16.0 m.
- 5 Clay, black, upper 7-10 cm. finely laminated and dark gray; sieve residue composes 10% of total sieve sediment sample and consists of 100% plant material and <1% annelids; sample collected at a depth of 20.7 m.
- 6 Clay, black to dark brown; sieve residue composes 5-10% of total sieve sediment sample and consists of 100% plant material and 1% annelids; sample collected at a depth of 15.0 m.
- 7 Clay, black; sieve residue composing 3-5% of total sediment sample and consists of 93-98% plant material and 1-2% annelids; sample collected at a depth of 9.0 m.

Fayetteville Green Lake, New York

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, dark gray to black, H ₂ S-rich; sieve residue consists of 100% plant

material, <1% gastropod shells, and <1% pebbles; sample collected at a depth of 48.7 m.

- 2 Clay, dark gray to black, H₂S-rich, the sediment is cyclic laminated with alternating light and dark 2 mm. laminae; sieve residue consists of 100% plant material, <1% gastropod shells, and <1% calcite tubes; sample collected at a depth of 52.3 m.
- 3 Clay, dark gray to black, H₂S-rich; sieve residue composes 3-5% of total sieve sediment sample and consists of 90-95% plant material, 3-5% gastropod shells, and <1% calcite tubes and tufa particles; sample collected at a depth of 51.8 m.
- 4 Clay, dark gray to black, H₂S-rich, the sediment is cyclic laminated with alternating light and dark 2 mm. laminae; sieve residue consists of 90-95% plant material, 2-3% gastropod shells, and 1-2% calcite tubes and tufa particles; sample collected at a depth of 53.8 m.
- 5 Clay, dark gray to black, H₂S-rich, sediment is cyclic laminated with alternating light and dark 2 mm. laminae; sieve residue consists of 80% plant material, 15-20% calcite particles, and 1-2% gastropod shells; sample collected at a depth of 54.0 m.
- 6 Clay, dark gray to black, H₂S-rich, sediment is cyclic laminated with alternating light and dark 2 mm. laminae; sieve residue consists of 80-85% plant material and 10-15% gastropod shells; sample collected at a depth of 38.8 m.
- 7 Clay, dark gray to black, H₂S-rich; sieve residue composes 15% of total sieve sediment sample and consists of 95% plant material, 3-5% gastropod shells, and <1% calcite particles; sample collected at a depth of 22.6 m.

- 8 Clay, dark gray to black, H₂S-rich; sieve residue composes 60% of total sieve sediment sample and consists of 95% plant material, and 3-5% gastropod shells; sample collected at a depth of 14 m.

Dark Lake, Wisconsin

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, dark brown; sieve residue composes 2-3% of total sieve sediment sample and consists of 100% plant material and <1% insect remains; sample collected at a depth of 18.6 m.
2	Same as sample 1 except without insect remains; sample collected at a depth of 12.0 m.
3	Same as sample 2; sample collected at a depth of 15.0 m.
4	Same as sample 2; sample collected at a depth of 17.8 m.
5	Same as sample 2; but sieve residue composes 10-15% of total sieve sediment sample; sample collected at a depth of 4.0 m.

Little Pine Lake, Wisconsin

<u>SAMPLE</u>	<u>DESCRIPTIONS</u>
1	Clay, dark green to black, partly laminated, H ₂ S-rich; sieve residue composes 3-5% of total sieve sediment sample and consists of 100% plant material; sample collected at a depth of 16.8 m.
2	Same as sample 1 but did not observe laminated sediment; sample collected at a depth of 16.3 m.

- 3 Same as sample 2; sample collected at a depth of 11.8 m.
- 4 Same as sample 1; sample collected at a depth of 17.8 m.
- 5 Same as sample 2; sample collected at a depth of 7.2 m.
- 6 Same as sample 2; sample collected at a depth of 8.8 m.
- 7 Same as sample 1; sample collected at a depth of 11.4 m.

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