BIOMONITORING AND USING CHIRONOMIDAE AS ENVIRONMENTAL INDICATORS IN FOUR WISCONSIN LAKES

Bios 569 - Practicum in Aquatic Biology

Brian Foy
247 Dillon Hall
Dr. Ronald A. Hellenthal
1993

Abstract

Four lakes in northern Wisconsin are analyzed physically, chemically, and biologically. Although all are part of the same drainage basin and some actually flow into the others, their differences are noticeable. The lakes were mapped and physical parameters were calculated. Dissolved oxygen concentrations and stratification are a primary difference among these lakes. The chemical analysis was highlighted by differences among nutrient, sulfide, and alkalinity concentrations. These factors allowed for determination of the lakes' trophic levels and possible trends. The data was further enhanced by the biomonitoring of Chironomidae from the benthos. Intrataxon variation between the Chironomidae also produced interesting results such as size selection and time of maximal density.

Chironomid Biomonitoring in Four Lakes

Introduction

Physical, chemical, and biological parameters are used to categorize all bodies of water. Lakes are often grouped by size, pH, or even the fish that they contain. Physical, chemical, and biological parameters, when used holistically, are important in determining the overall trophic classification of the lake (oligotrophic to eutrophic). Oligotrophic waters are characterized by: cold, deep waters; low nutrient compositions; a diverse plant an animal community; deep-dwelling, cold water fishes; and a high oxygen content in the hypolimnion. On the other hand, eutrophic waters are marked by: warmer, shallower waters; high nutrient compositions; fewer faunal and floral species; shallow-dwelling, warm water fishes; and a low oxygen content in the hypolimnion (Ryding and Rast 1989). The natural progression of lakes from an oligotrophic form to a eutrophic form is complicated by the fact that lakes assume other forms, such as dystrophic and meromictic forms, which are common for bog lakes. When particular combinations of climatic conditions, vegetation, soil, and topography favor the formation of peat deposits, bog lakes form (Welch 1952). Bog lakes pH values are typically acidic. The waters also tend to be brown because of the abundant humic acid colloids, which form a flocculent fake bottom overlying the peat deposits (Ward 1992). The natural pH of lentic waters are largely determined by H^+ ions from disassociation of H_2CO_3 and from ^-OH produce by hydrolysis of bicarbonate. Low pH in some lakes is due to dissolved organic matter. The very low pH of bog lakes, however, is due to the moss *Sphagnum*. Most of the H^+ ion concentrations are the result of active cation exchange by the cell walls of the *Sphagnum* (Wetzel 1983). It is important to note here, that bogs are not a stage of eutrophication through which a lake must pass, but they are a separate class of waters with unique environmental conditions.

Classification and categorization of lakes using benthic macroinvertebrates, specifically Chironomidae, began in the early 20th century (Thienemann, 1922; Rosenberg, 1992). Biomonitoring, the monitoring of organisms as environmental stress indicators, grew from these roots. However, biomonitoring has not grown as an important, recognized field until recently. In 1988, the Ecological Society of America finally recognized biomonitoring as a priority in their ecological research agenda for the closing decade of the 20th century. The E.S.A. writes, "In some ecosystems, functional measurements of ecosystem processes (such as productivity and nutrient cycling) are often less sensitive indicators of ecosystem stress than are structural properties such as species composition (Schindler 1987)." (Lubchenco et al. 1991). Biomonitoring for indicators of an ecosystem's response to stress and for baseline variability of indicators in ecosystems, however, did not come about until initial classification schemes using biological indicators developed. Thienemann's work was seen as the beginning of classification of lakes by trophic types and even limnology as a science (Saether 1979). Others took Thienemann's work and expounded on it, increasing the number of trophic levels and the divisions of chironomid taxa (Lenz, 1936-Brundin,1949; Saether, 1979). Soon indexes appeared using mathematical formulas to summarize chironomid data and tie it to chemical factors and eutrophication (Pantle and Buck-1955, Brinkhurst et al.-1968, and Wiederholm-1976). The general use of aquatic insects as indicators of trophic levels and water quality indicators is ideal because they reflect conditions through time even after the physical or chemical changes have disappeared. They also integrate all the environmental conditions occurring, whereas without biomonitoring, one would need to examine each condition separately (Hellenthal 1982). Family Chironomidae is specifically advantageous for biomonitoring in that chironomids are an extremely diverse taxa and they exhibit a wide range of environmental tolerances (Rosenberg 1992). Recently, qualitative approaches to biomonitoring has been the norm for water quality assessment. Called 'rapid assessment techniques', these measures are used to keep analyzing and testing costs low. Different rapid assessment techniques include: taxa richness, enumeration, community diversity and community similarity indices, biotic indices, functional feeding groups, and combinations of the above (Rosenberg 1992). However, to ensure accurate results in any biomonitoring, several biotic groups should be used concurrently along with physical and chemical data (Rosenberg and Resh 1993).

Materials and Methods

Morris, Ward, Mullahy, and Reddington lakes occur on the north central border of the University of Notre Dame Environmental Research Center's property (UNDERC). The UNDERC property is located in the northern temperate forest region of northern Wisconsin. The lakes create a separate drainage basin from the rest of the property's lakes. Mullahy flows into Ward via a small channel. Together, these lakes seep into Morris lake as does Reddington. All the ground seepage of the property eventually is collected into Tenderfoot Creek and carried off the grounds. The four lakes were analyzed through physical, chemical, and biological means by Bridget Graham, Amy Christensen, and myself. Physical analysis was based on the sonar mapping of the lakes with a Bottomline Tournament 310EL series fish-finder. Transects across each lake were made keeping in line with a compass as the sonar read distance traveled and depth readings. Plots were drawn by hand and scanned into computer to be resolved. Surface area, volume, etc. was calculated using the computer resolved maps. Temperature and dissolved oxygen readings were taken together on two separate dates over the summer with a YPI dissolved oxygen meter. Chemical data was acquired by sampling lake water in plastic bottles. The water was brought back to the lab and analyzed using Hach chemicals for alkalinity, color, conductivity, nitrate, phosphate, and sulfide. A Hach pH meter was used to measure pH.

Biological analysis of the lakes was divided into flora, zooplankton, and insect studies. I analyzed the benthic insect fauna with particular emphasis on the family Chironomidae. Substrate was sampled on two dates of the summer using an Ekman grab. Contents were sifted immediately with a 250 micron sieve and put in labeled plastic bags with 95% ETOH. Preserved organisms were later picked by hand under a microscope from the sieved substrate. Chironomids were identified to subfamily and tribe, all other insects were identified to family using Merrit and Cummins (1984). Data analysis (Cluster analysis and corresponding dendrograms) was done using Systat Version 5.02 (Wilkenson 1990). Variables used were the average density of each chironomid family per lake. Dendrograms drawn are based on the relatedness of the average chironomid densities.

Results

Physical Data Results.

All the lakes were mapped with the sonar, yet only Mullahy and Reddington are presented because Morris and Ward maps are already on file. Mullahy (fig. 1) is a shallow lake all the way across. It turns out to be the smallest of the four lakes. Being so small and shallow, Mullahy's temperature is warm throughout and the % oxygen saturation is rather consistent (figs. 2,3). Mullahy doesn't have a detectable hypolimnion because of these factors. Morris and Ward are similar lakes in comparison to their unrelated sizes. Although Morris is larger in diameter, they both have similar depths and the temperature and oxygen profiles followed typical curves as one measured through the metalimnion and into the hypolimnion (figs. 4-7). Both lakes had well defined littoral and profundal zones as well. Reddington (fig. 8),

Fig. 1

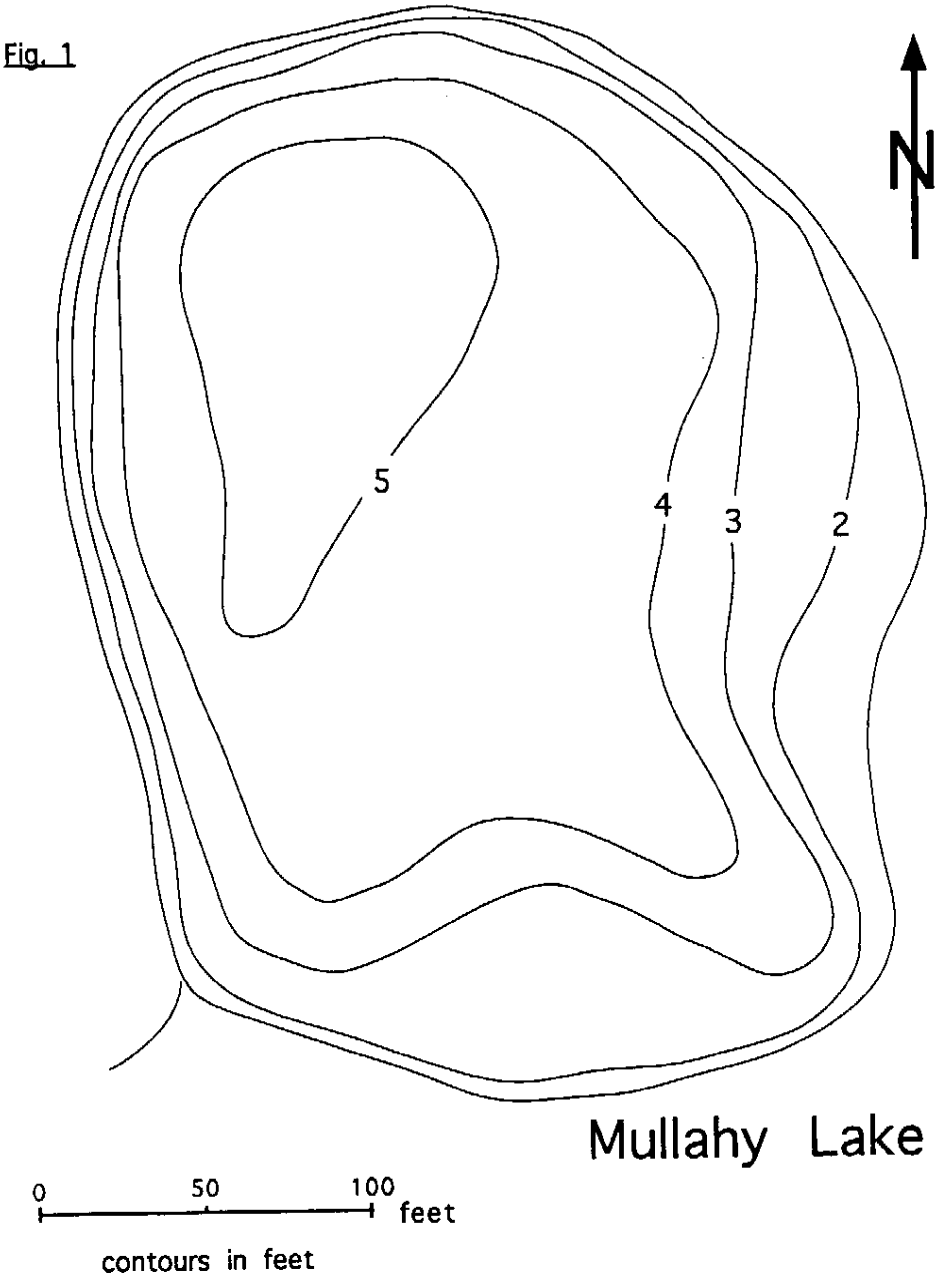


Fig. 2

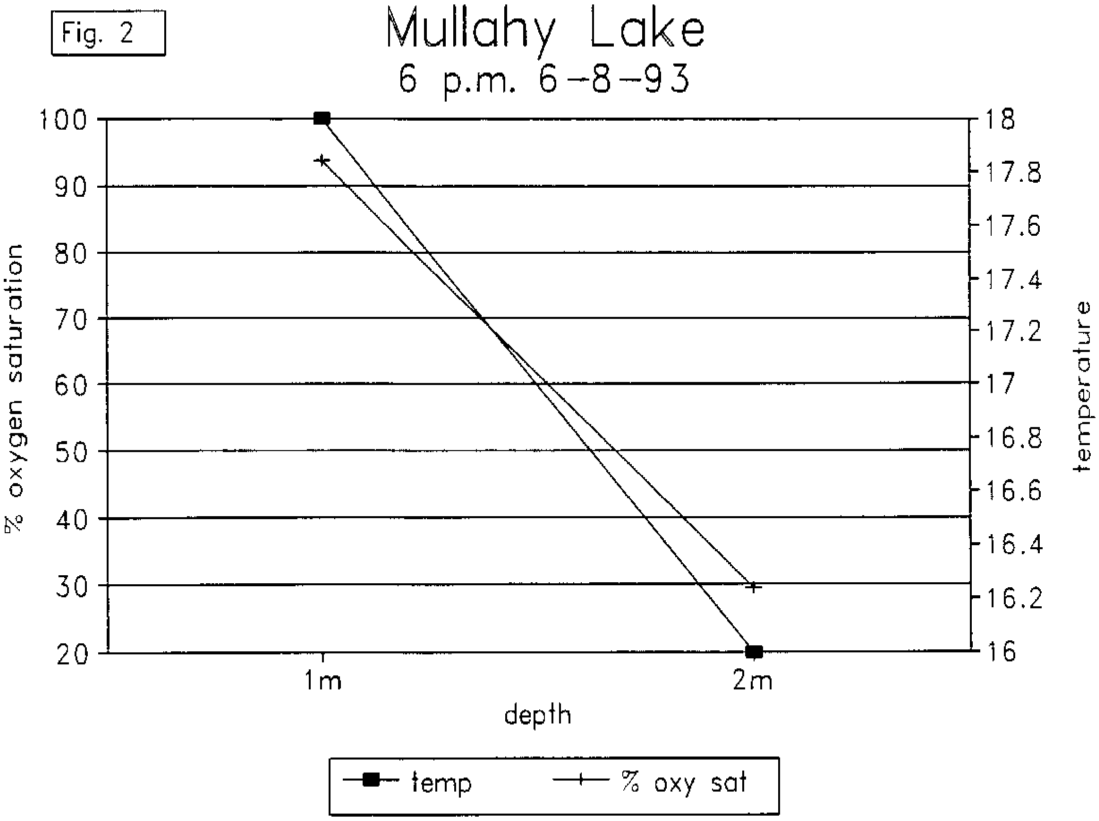

Mullahy Lake
6 p.m. 6-8-93
100
90
80
70
60
50
40
30
20
% oxygen saturation
18
17.8
17.6
17.4
17.2
17
16.8
16.6
16.4
16.2
16
temperature
1m
2m
depth
temp
% oxy sat

Fig. 3

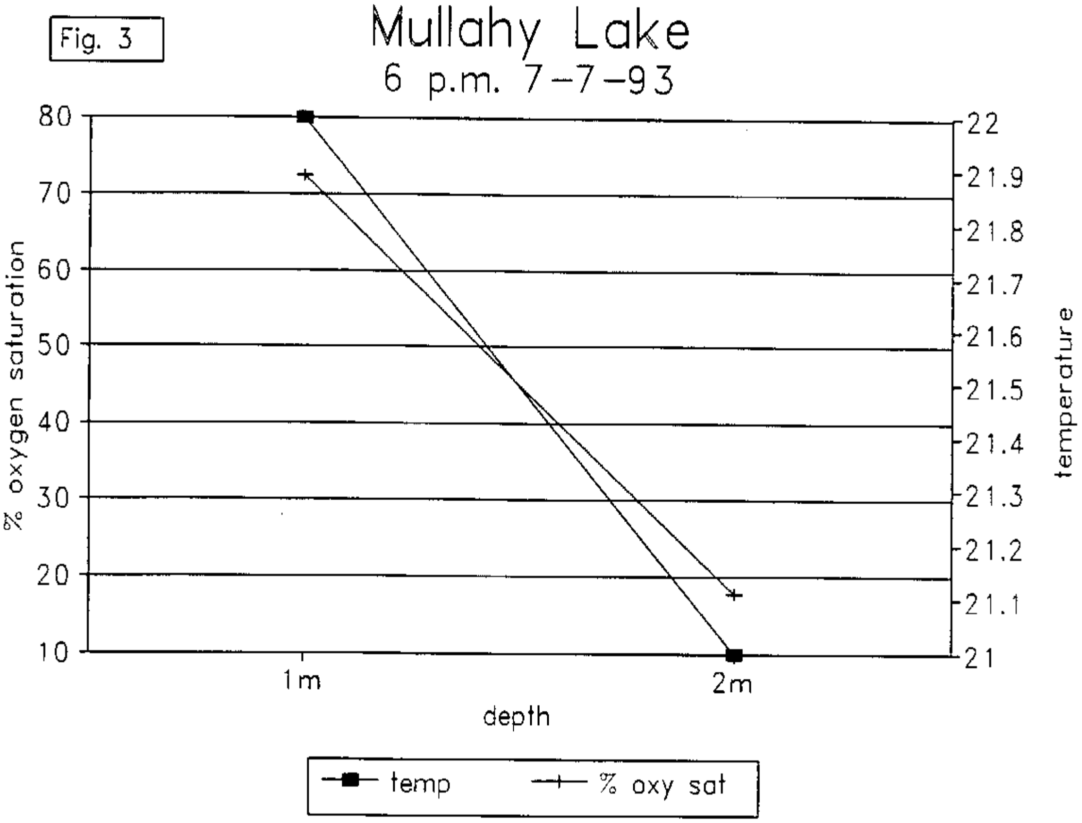

Mullahy Lake
6 p.m. 7-7-93
80
70
60
50
40
30
20
10
% oxygen saturation
22
21.9
21.8
21.7
21.6
21.5
21.4
21.3
21.2
21.1
21
temperature
1m
2m
depth
temp
% oxy sat

Fig. 4

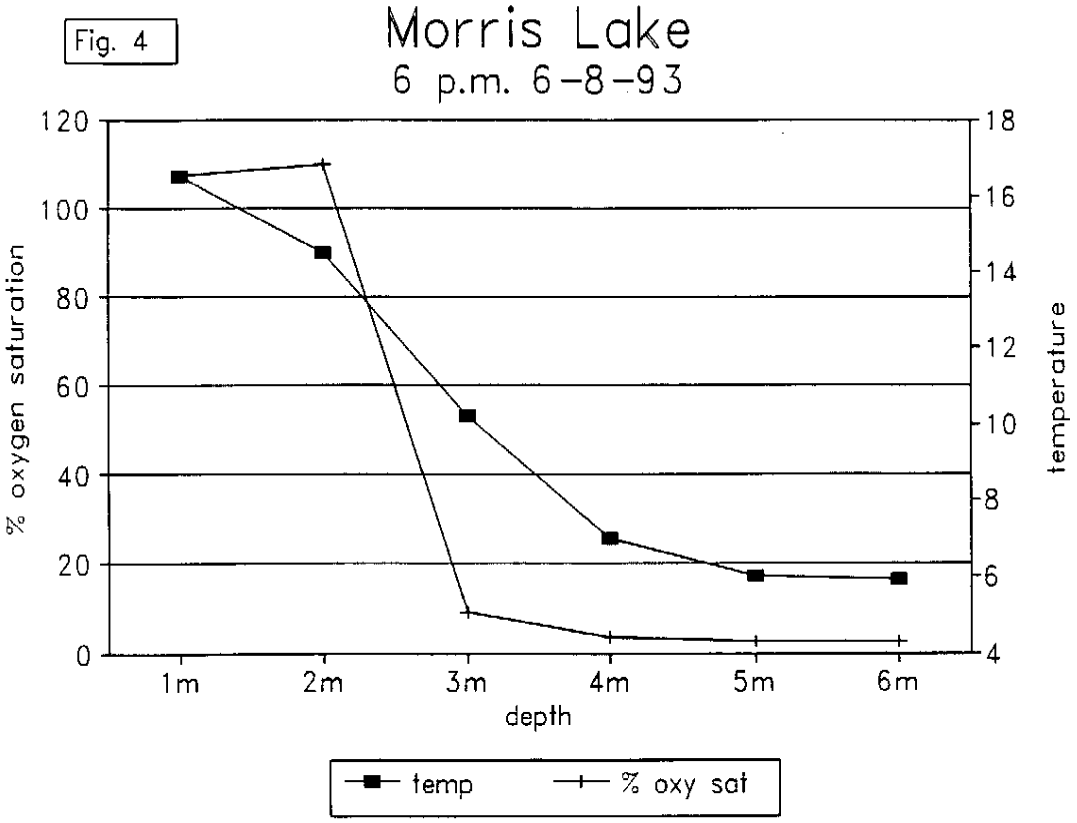

Morris Lake
6 p.m. 6-8-93
% oxygen saturation
120
100
80
60
40
20
0
temperature
18
16
14
12
10
8
6
4
1m
2m
3m
4m
5m
6m
depth
temp
% oxy sat

Fig. 5

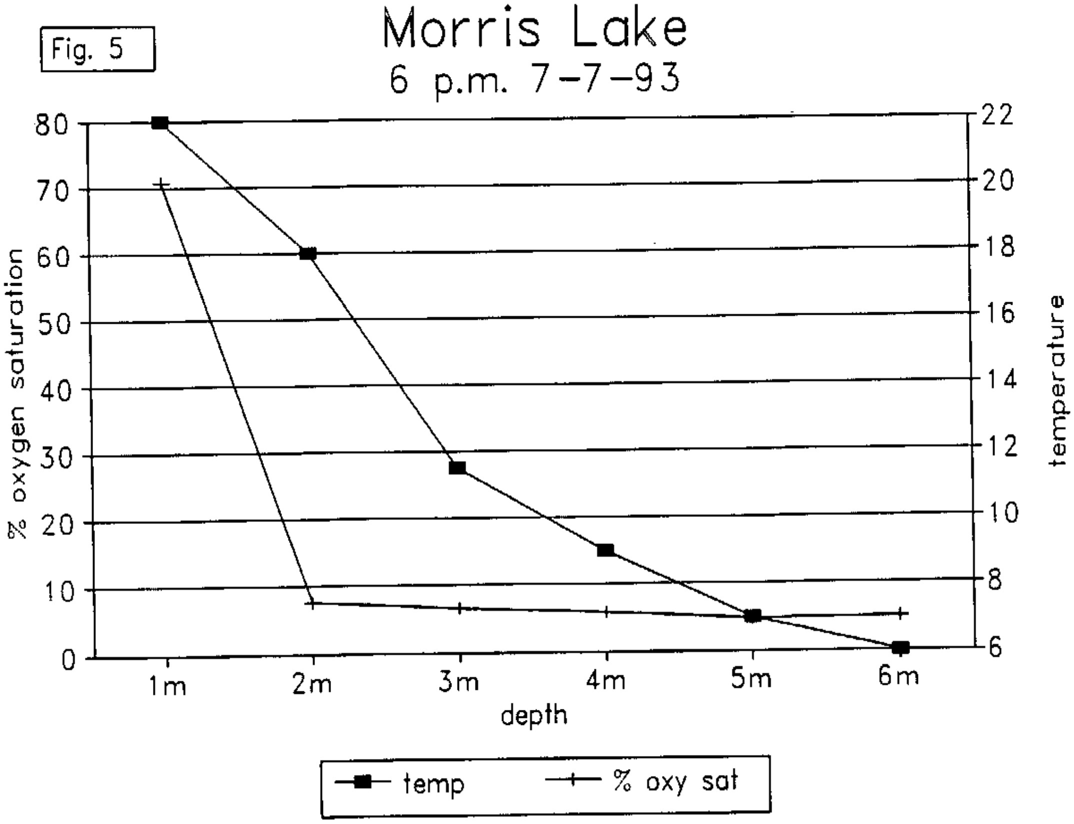

Morris Lake
6 p.m. 7-7-93
% oxygen saturation
80
70
60
50
40
30
20
10
0
temperature
22
20
18
16
14
12
10
8
6
1m
2m
3m
4m
5m
6m
depth
temp
% oxy sat

Fig. 6

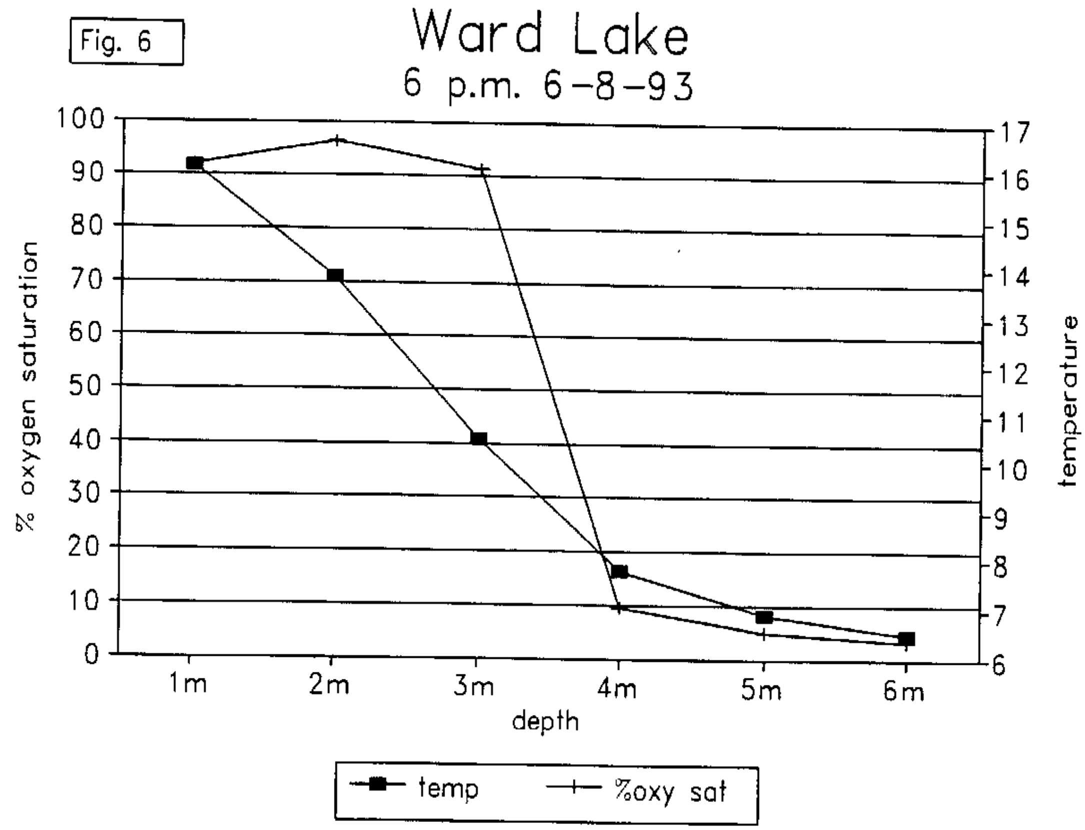
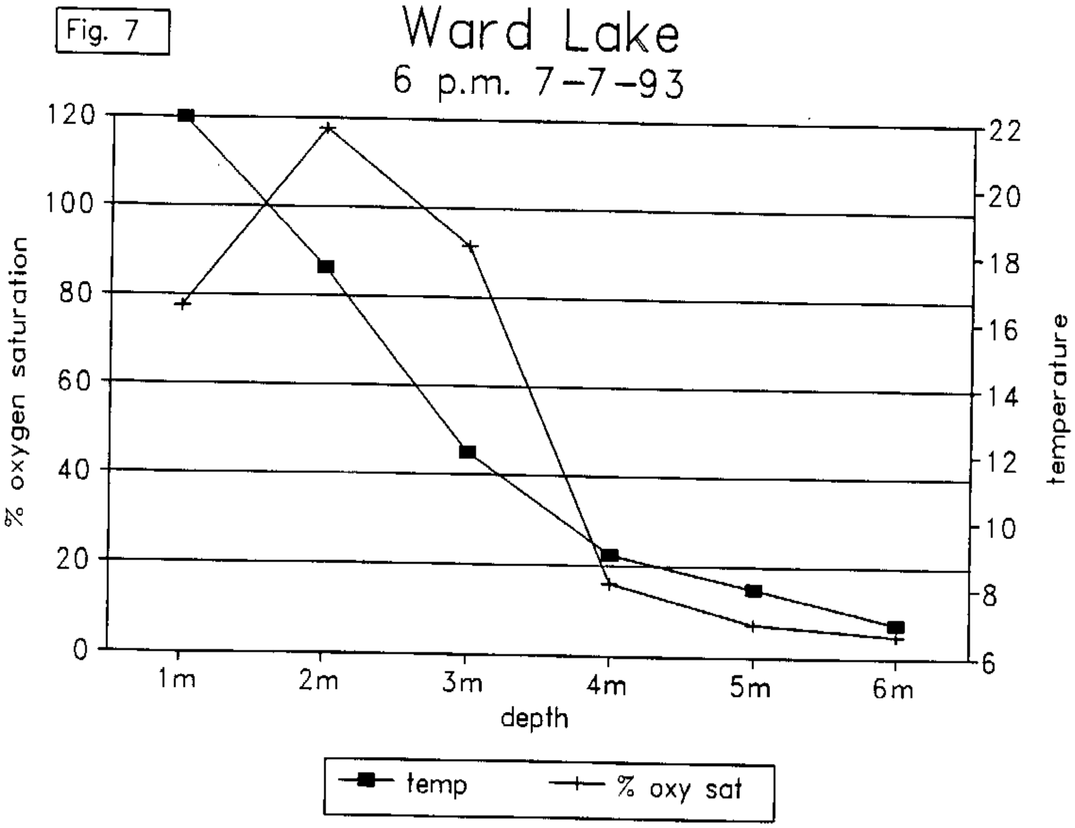

Ward Lake
6 p.m. 6-8-93
% oxygen saturation
100
90
80
70
60
50
40
30
20
10
0
temperature
17
16
15
14
13
12
11
10
9
8
7
6
1m
2m
3m
4m
5m
6m
depth
temp
%oxy sat

Fig. 7


Ward Lake
6 p.m. 7-7-93
% oxygen saturation
120
100
80
60
40
20
0
temperature
22
20
18
16
14
12
10
8
6
1m
2m
3m
4m
5m
6m
depth
temp
% oxy sat

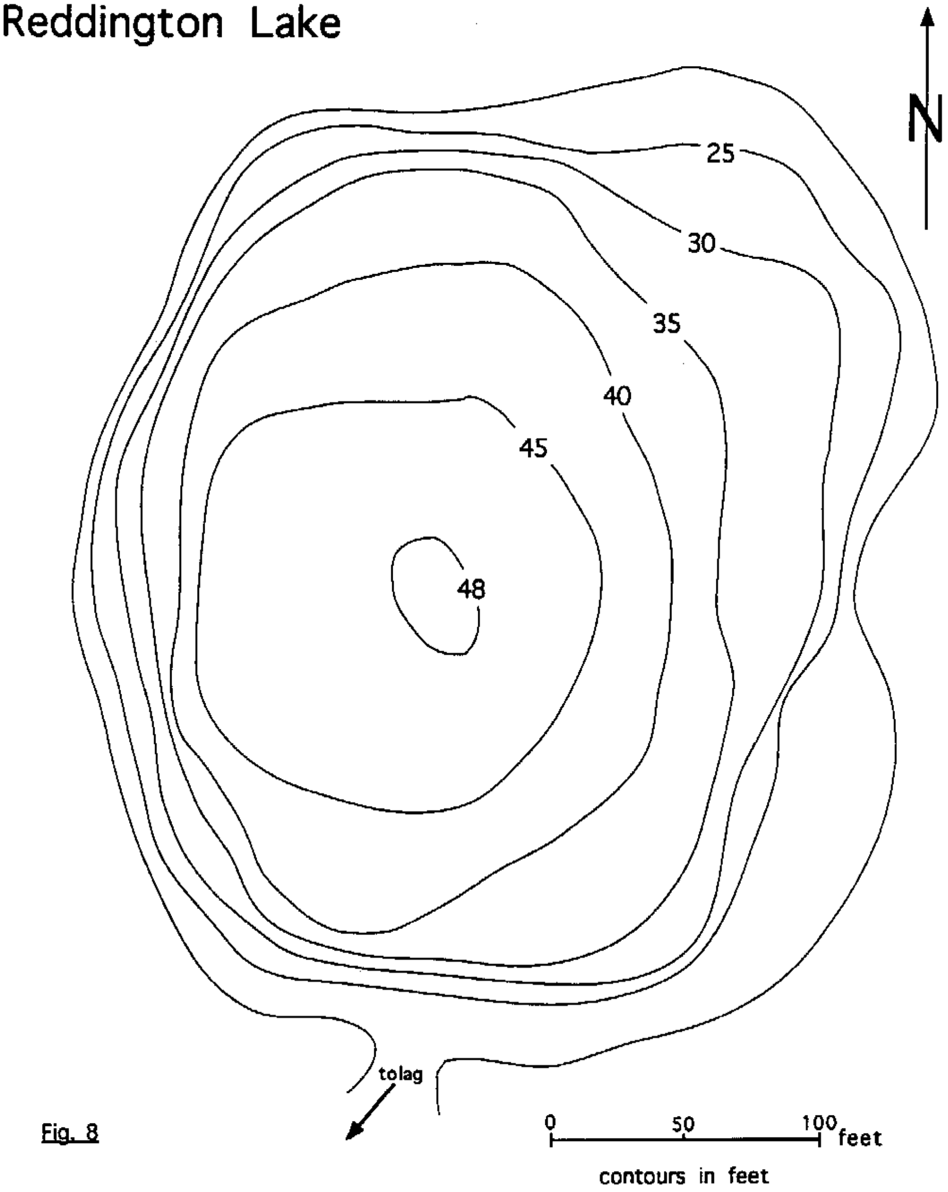

Reddington Lake
N
25
30
35
40
45
48
tolag
0
50
100
feet
contours in feet

Fig. 8

however, turned out to be a most unusual body of water. It is actually a quaking bog with an overgrowing *Sphagnum* mat and a lag around it. Reddington also turned out to be unusually deep and had strange temperature and D.O. profiles (figs. 9,10).

Chemical Data Results.

Water samples used for chemical analysis of the lakes were taken shallow (just below the surface) and deep (1m off the surface) and all in the pelagic zone. Therefore, I present only the deep water analysis (table 1, figs. 11,12) because of its far greater effect on the benthic invertebrates that are the primary focus of this paper. The measured pH is of some suspect because it was measured through a Hach ph monitor that was not reading correctly at times throughout the summer. The pH's of some the lakes do not correlate well with previous years' measurements and the measurement on Reddington's water is significantly greater than would be expected.

Biological Data Results.

Initial biological comparisons were to include all benthic insects, their relative numbers to each other and taxa present. Results, however, produced only five organisms other than chironomids in all the lakes combined (excluding Chaoboridae residing near the bottom). Three Phryganeidae (family), *Agrypnia sp.* were found, two in Mullahy and one in Morris. Several *Agrypnia sp.* cases were also found. The other two organisms found, one in Morris, the other in Mullahy, were Caenidae (family), *Caenis sp.* Family Chaoboridae, *Chaoborus sp.* also were found in the Ekman samples but are, in actuality, an invertebrate of the water column. All other benthic invertebrates discovered were of Family Chironomidae. Chironomids were subsequently divided into Subfamily Tanypodinae, Subfamily Orthocladiinae, Tribe Chironomini, and Tribe Tanytarsini. Average densities in each lake for both sampling dates are shown in figure 13. Due to time limitations, only five of the original ten samples taken during the second sampling were examined. The densities for these five samples were then doubled for the results to match the ten samples examined in the previous time period. Average densities were also multiplied by 43.1 to convert the densities to m^2. Morris lake had the most chironomids per square meter, with particularly a high number of Chironomini (Chironomus sp.). Mullahy and Ward had a relatively higher number of Tanytarsini and Tanypodinae. Reddington turned out to be devoid of all benthic macroinvertebrates. Cluster analysis based on average densities (figs. 14,15) separated Morris lake the most. Mullahy and Ward were fairly related, while Reddington branched out from these two lakes.

Fig. 9

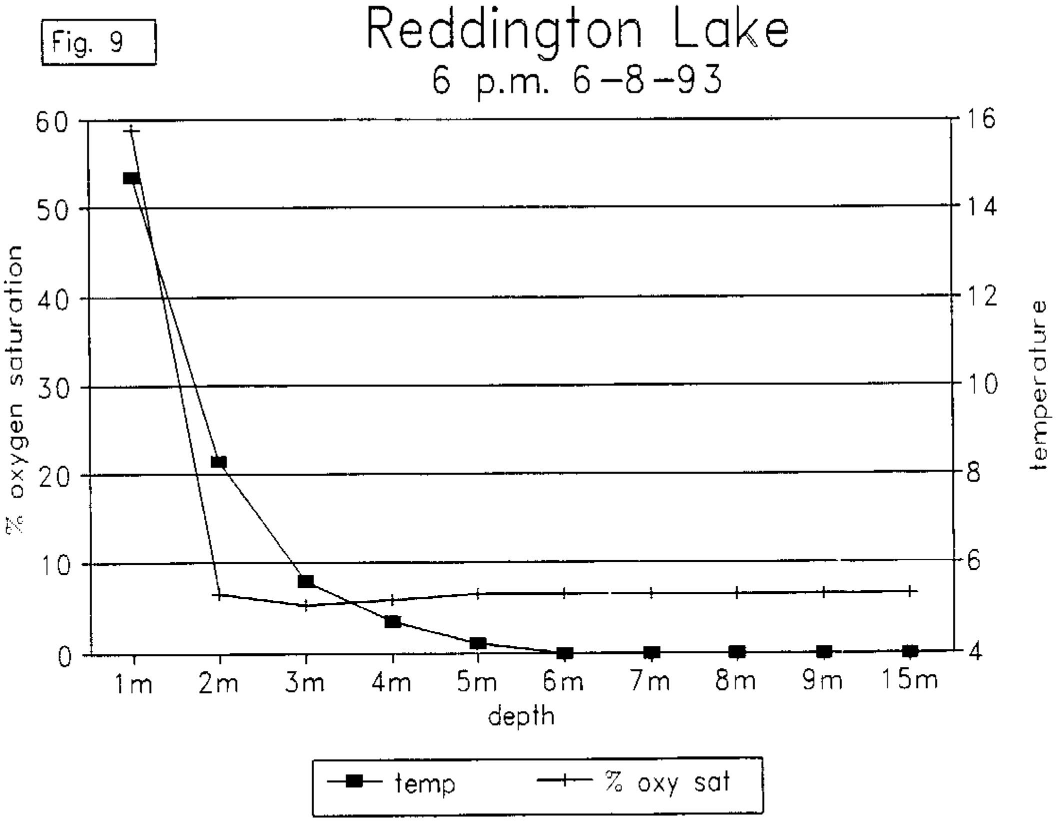

Reddington Lake
6 p.m. 6-8-93
60
50
40
30
20
10
0
% oxygen saturation
16
14
12
10
8
6
4
temperature
1m
2m
3m
4m
5m
6m
7m
8m
9m
15m
depth
temp
% oxy sat

Fig. 10

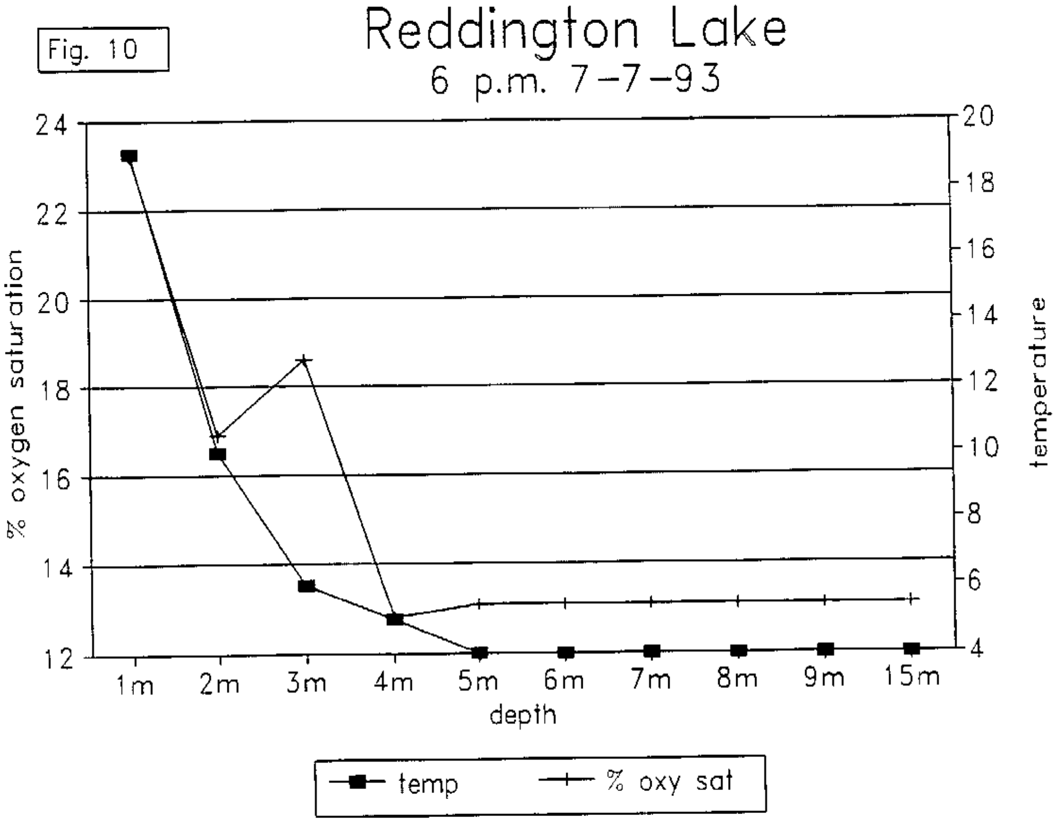

Reddington Lake
6 p.m. 7-7-93
% oxygen saturation
24
22
20
18
16
14
12
temperature
20
18
16
14
12
10
8
6
4
1m
2m
3m
4m
5m
6m
7m
8m
9m
15m
depth
temp
% oxy sat

Table.1

Lake Chemistry Measurements for Deep Waters

Lakes	alkalinity	pH	color	conductivity	nitrate	phosphate	sulfide
Morris	46 mg/L	6.78	178	0.1 u MHO	0	0.12 mg/L	0
Ward	142mg/L	7.15	257	0.28 u MHO	0	0.05 mg/L	0
Mullahy	42mg/L	7.2	74	0.03 u MHO	0	0.03 mg/L	0
Reddington	12 mg/L	6.7	203	0.04 u MHO	0.02 mg/L	0.05 mg/L	0.5 mg/L

Table.2

Physical Data for Mapped Lakes

	Mullahy	Reddington
surface area (acres)	1.2	1.7
(sq. ft.)	52,272	72,536
length of shoreline (ft.)	975	1160
shore development	1.2	1.2
mean breadth (ft.)	149	181
max. length (ft.)	350	400
max. depth (ft.)	5	48
volume (ft.)	185,773	2,432,092
mean depth (ft.)	3.6	33.5

Fig. 11

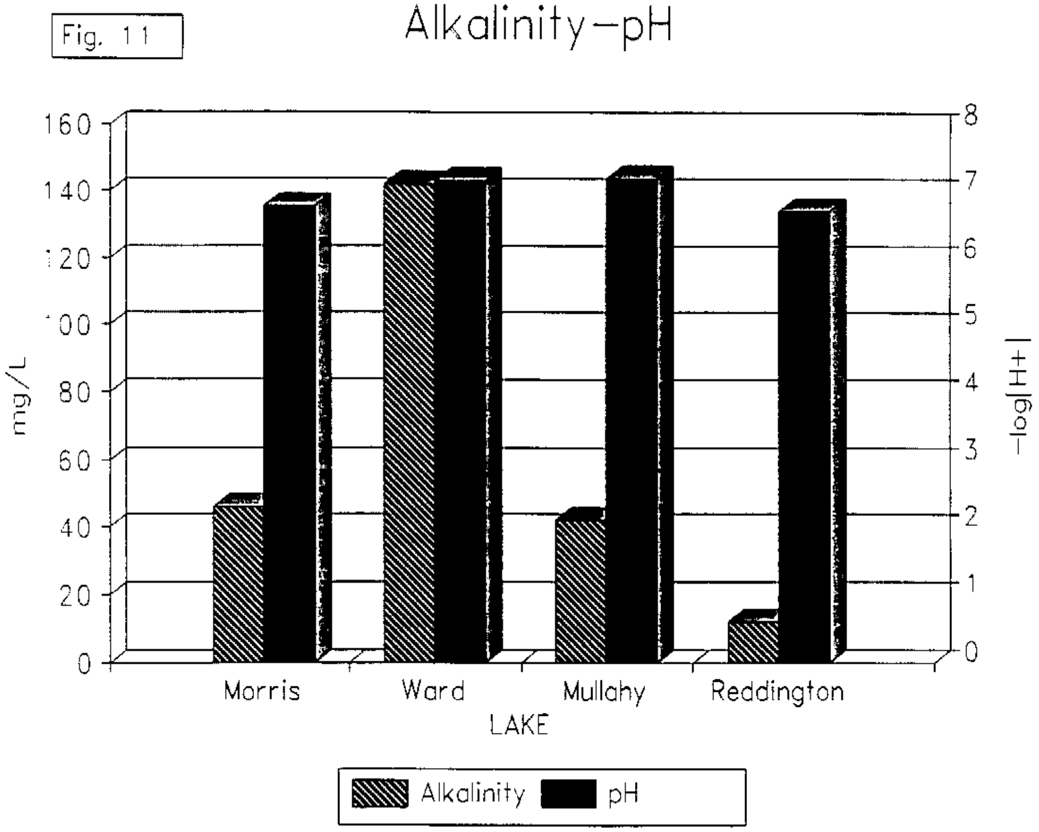

Alkalinity–pH
160
140
120
100
80
60
40
20
0
mg/L
8
7
6
5
4
3
2
1
0
–log[H+]
Morris
Ward
Mullahy
Reddington
LAKE
Alkalinity
pH

Fig. 12 Nitrate–Phosphate–Sulfide

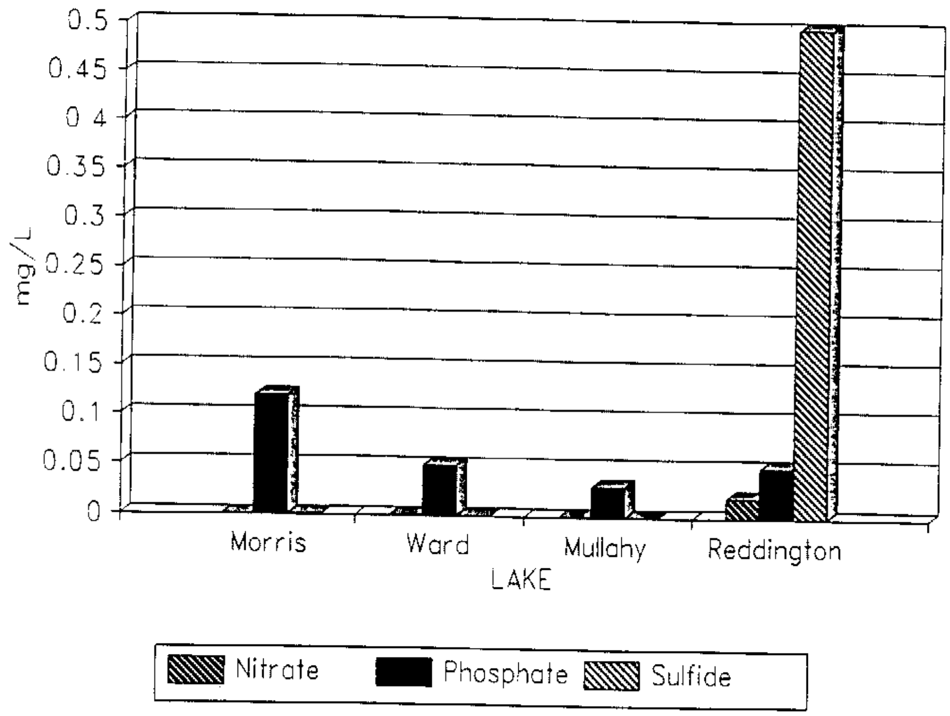


Fig. 13

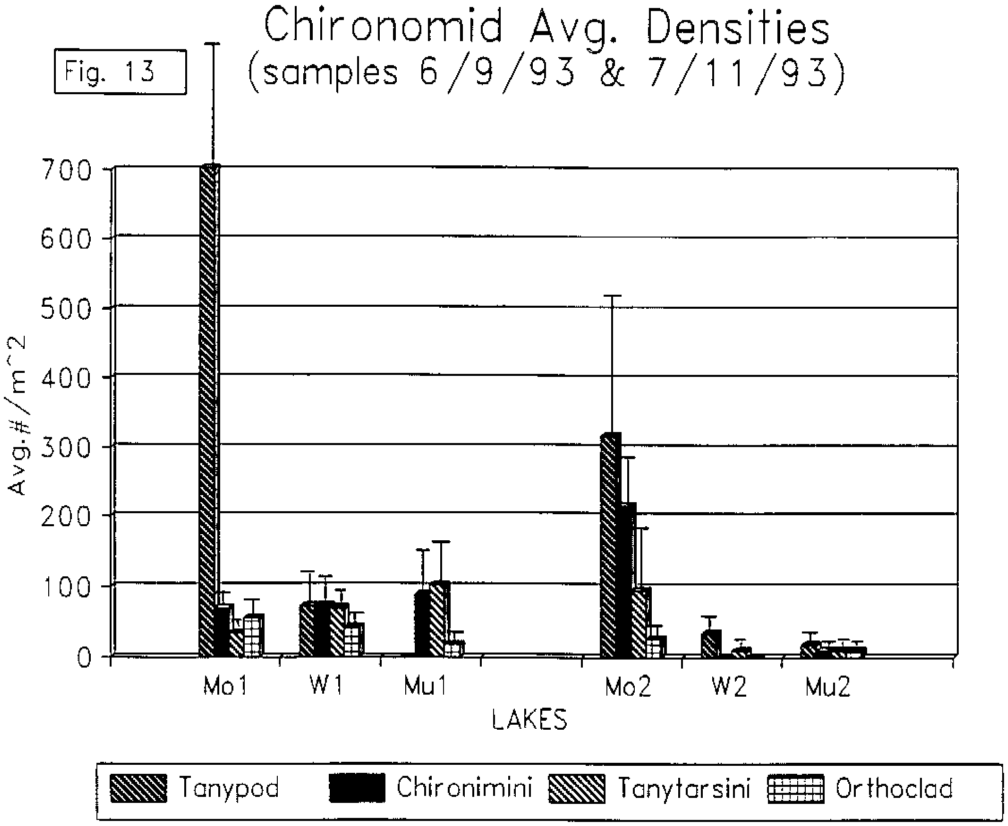

Chironomid Avg. Densities
(samples 6/9/93 & 7/11/93)
Avg.#/m^2
700
600
500
400
300
200
100
0
Mo1
W1
Mu1
Mo2
W2
Mu2
LAKES
Tanypod
Chironimini
Tanytarsini
Orthoclad

Fig. 14

Cluster Analysis Dendrogram
(samples taken 6/9/93)

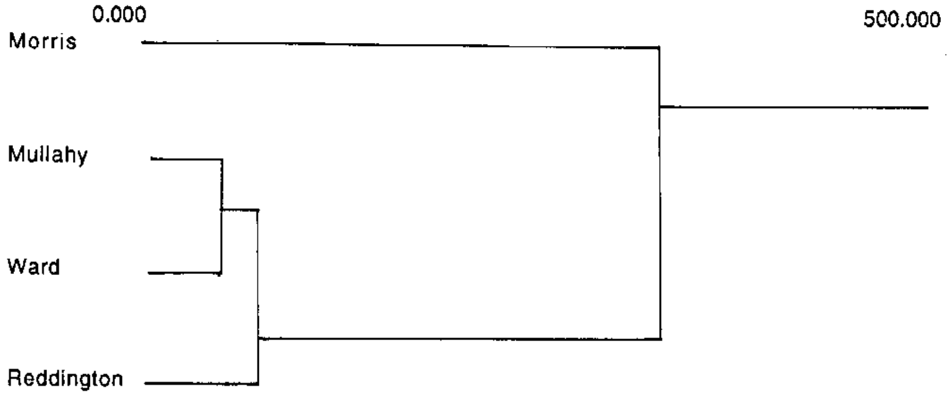
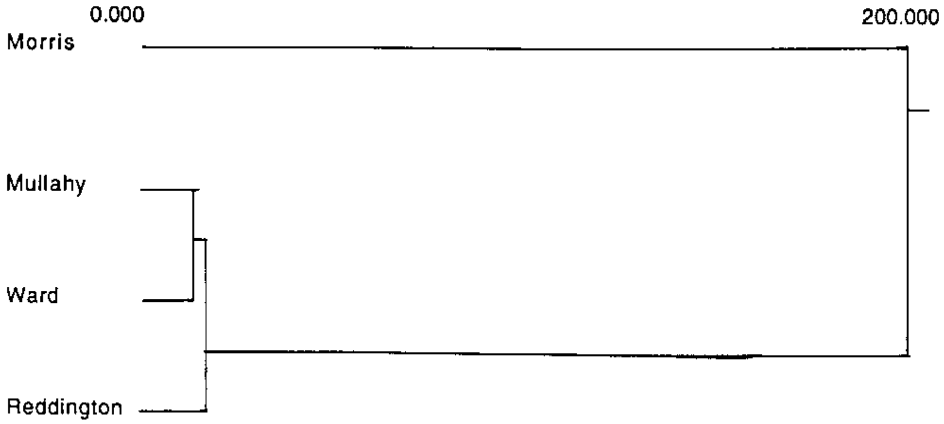


Fig. 15

Cluster Analysis Dendrogram
(samples taken 7/11/93)



Discussion

In reviewing all of the lakes on the UNDERC property, it seems that only one lake, Brown lake, would be considered a eutrophic lake from nutrient and biological standards. Most other lakes are mesotrophic with the possible exception of Crampton or Roach, which lean toward oligotrophic. The other boggy lakes on the property are considered dystrophic because of the very nature of bog waters. Eutrophication is synonymous with the increased growth rates of biota in a lake (Wetzel 1983). However, no other lakes besides Brown have significantly eutrophied. Mentioned before was the change in the life cycle of a lake that sometimes, under the right environmental conditions, never becomes eutrophic but turns dystrophic. This is primarily due to the input of organic matter with a high humic content. It seems reasonable that the primary pathway of the aging of the lakes I studied, and the lakes on the UNDERC property, is from oligotrophic to dystrophic lakes and bogs. There are several observations which support my theory. Apart from the visible growth rates of biota in lakes, the primary factor in the eutrophy of lakes is productivity. The most important nutrient factors controlling the shift from a lesser to a more productive lake are nitrogen and phosphorus levels. Oligotrophic lakes are limited by phosphorus and have often have an excess of nitrogen (Wetzel 1983). Figure 11 shows that the nitrate levels of three of the lakes are zero. Phosphate levels on the other hand range from 30-120 u mg/L, a figure consistent with the general phosphate levels of eutrophic lakes (Ryding and Rast 1989). Morris, Mullahy, and Ward nutrient levels are typical of eutrophic lakes. Their oxygen stratifications (figs. 3-8) are also typical of eutrophied lakes. Yet, not one shows increased biotic growth or algal blooms and general productivity that occur in eutrophic lakes.

Reddington is a special case that needs more analysis. Reddington is a quaking bog as shown from the morphology, high hypolimnetic sulfide content, and presumably acidic waters. The problem is of Reddington's unusual depth, oxygen and thermal stratification (figs. 9,10). Reddington's epilimnion is only about 1m deep. The % oxygen saturation and temperature drop drastically after 1m. Also, no significant change occurs in these profiles from one time sampling to the other. The other lakes show an increase in bottom temperatures and a decrease in oxygen as time passes. This is typical due to the mixing and then stratification of waters after 'ice-out' and the spring overturn. It is quite possible that Reddington is a meromictic lake, meaning it does not undergo circulation. If it is meromictic, it is most likely a biogenic meromixis. Biogenic meromixis is due to the concentration of salts in the monimolimnion released from decomposition and sedimenting of organic matter (Wetzel 1983), which is great in the flocculent false bottom of Reddington. Biogenic meromixes is also frequent in deep lakes, such as Reddington.

The results of the benthic sampling from the lakes were initially surprising. It was thought that many other orders and families of insects would have been found besides the Chironomidae. It would seem that there are others present from seeing emergences of dragonflies, mayflies, etc., but that our sampling was not nearly rigorous enough. An Ekman grab with a tiny area, sampling the profundal zone of a lake as large as Morris can not accurately predict the benthos, unless the organism's density is great. Chironomids frequently make up 90% of the benthos of lakes (Wiederholm 1977). All the other benthic insects do not have nearly as great densities. However, the 3 Phryganeids and 2 Caenids can still be useful in correlating data. Hilsonhoff's biotic index (1987), gives both Phryganeidae, *Agrypnia sp.* and Caenidae, *Caenis sp.* a tolerance value of 7 (for the degree of organic pollution, 0=poor and 10=excellent). This would correspond to the significant amount of allochthonous 'pollution' present in the lakes.

Family Chironomidae can always tell a significant amount about the environment because they are so ubiquitous, abundant, and sensitive to specific conditions. Thienenmann (1922), and Brundin (1949) popularized the view: "Tanytarsini=oligotrophic and Chironomini=eutrophic", meaning that these tribes are general indicators of the trophic level of lakes. Wiederholm (1980), Saether (1979), and others further refined this system by narrowing indicators to genus and species and by subdividing trophic levels. Time did not permit identifying to these lower levels but general conclusions can still be inferred. Chironomini, *Chironomus sp.* were highly abundant in Morris lake compared to other taxa in Morris and to the relative number of Chironomini in the other lakes. These results would correlate with the literature if we hold that Morris is a mesotrophic-tending-to-dystrophic lake. Wiederholm and Johnson (1989) report that in fact *Chironomus sp.* were indicative of dystrophic, poorly buffered lakes. *Chironomus sp.* are also called bloodworms because of their haemoglobin content. Haemoglobin and the presence of caudal gills aid in respiration in oxygen deficient waters which are greater in Morris because of its depth.

Tanytarsini vary with the different lakes, but not significantly with the errors included to extrapolate any results. Typically they are associated with oligotrophic lakes that are well buffered (Weiderholm and Johnson 1989). Ward's data suggests that Tanytarsini equal in number to the Chironomini. Although the Tanytarsini traditionally represent an oligotrophic lake which Ward is clearly not, Ward's alkalinity is unusually high. The high alkalinity corresponds to a well buffered system due to bicarbonate. Thus, the Tanytarsini:Chironomini ratio in Ward might suggest the two conflicting aspects of a more eutrophied system but a well buffered system.

The Tanypodinae also show an interesting trend. Tanypodinae are generally considered predacious midges, preying mainly on other midges (Merritt and Cummins 1984). From the different sampling times in Morris, the Tanypods are the only group to increase later in the summer. This is most likely an optimization of time:food ratio for the predator. In the other lakes, the Tanypod:other Chironomidae ratio is more equal. Since the total available prey is very limited even from the first sampling time, it would be optimal for the predator (Tanypodinae) to be a its highest density when the prey are at their highest density.

Reddington was devoid of all benthic macroinvertebrates. Consequently, there is no chironomid density data on Reddington. This might be due to the low number of replicates taken. However, it is very likely that there is truly no bottom fauna. Reddington is highly anoxic, presumably acidic, and contains high sulfide levels. Although their are bog lakes with low acidity and Chironomids (Weiderholm 1977), these lakes are not meromictic and thus presumably do not have the extreme sulfide levels.

There are other interesting biomonitoring results that are important to the Chironomidae collected. Sizes of the chironomid larvae were not measured but can be inferred because in general Chironomini or the bloodworms are about 3x bigger than any other group. It has been determined in studies that often times large size is characteristic of eutrophic lakes and increased depth (Davies,1980; Rosenberg 1992). Dermott (1988) determined that the most important factor in controlling size was the presence or absence of fish (Rosenberg and Resh 1993). From figure 13, it is obvious that the Chironomini dominate in Morris, but are equal to the other chironomids in the other lakes. When examining the fish populations in Morris, Mullahy, and Ward, one sees a marked difference. As noted in the Guide to UNDERC and in our trap findings, Mullahy and Ward are dominated by bluegill and sunfish. These are benthic feeding fish that can eat up to 50% of their diet in Chironomids. On the other hand, Morris is dominated by piscivorous fish such as northern pike and large yellow perch. This would create a top-down affect, thus controlling the amount of benthic-feeding fish that eat the Chironomids. In Morris, the larger Chironomini would have a better chance of surviving as opposed to the ones in Mullahy and Ward as is shown in figure 13. The Chironomini of Morris would also, through selection pressures, tend to be (and are) of greater size in relation to each other than those found in Mullahy and Ward. This is oppositely true for the chironomids of Mullahy and Ward, which would be selected to be small to avoid fish predation.

Finally, Cluster analysis of the group density data for each lake reflected the results I have been discussing. The separation of Morris from the rest of the lakes due to it's Chironomini numbers. Mullahy and Ward are group as the closest lakes due to obvious number similarities. The problem with the analysis is its grouping of Reddington. Reddington with no fauna should be switched with Morris for it deviates from the others the most significantly. The Cluster analysis, however, only counts the numbers, and the high numbers of Morris differed more than the zeros of Reddington.

Conclusion

In Rosenberg's conclusion to his paper on biomonitoring with Chironomidae (1992), he states,"The value of integrated studies, using several biotic groups together with physical and chemical data, needs to be emphasized." I believed I have achieved an integrated biomonitoring study with this paper. Correlations drawn from physical, chemical, and biological factors show that all the lakes are mesotrophic to dystrophic in nature. Physical and chemical data present the unusual nature of Reddington and it's possible meromixis. Biological and physical results conclude that chironomid size is a selected factor in the lakes. Finally, biological and chemical figures show that benthic insects are lake indicators.

Further studies should be conducted into the actual character of Reddington. The nature of the bog was not known when the study started and so not all the right questions were asked of this bog. Other follow up studies should increase the sampling regime in the lakes and possibly better standardize the sampling technique. Finally, if time permits, one should further classify taxa so as to be more precise for lentic indicators.

Acknowledgements

I wish to acknowledge Amy Christensen and Bridget Graham who were my partners in the biomonitoring experiment. Harvey Leo, and all other UNDERCers who helped me with my sampling. Dr. Ronald Hellenthal, who helped me design my project. Marty Berg, who held my hand through it all. The Bernard J. Hank Family Endowment, and the Hanks for providing me with one of the most pleasurable and rewarding experiences of my life. And to all those whom I forgot to mention as a result of memory loss due to lack of sleep.

References

Brinkhurst R.O., A.L. Hamilton, and H.B. Herrington. 1968. Components of the bottom fauna of the St. Lawrence, GreatLakes. Great Lakes Institute, University of Toronto No. PR 33, 50 p.

Brundin, L.1949. Chironomiden und ander bodentiere der sudschwedischen urgebirgsseen. Inst. Freshw. Rsch. Drottningholm Report. 30:1-914.

Butler, M.G. and D.H. Anderson. 1990. Cohort structure, biomass, and production of a merovoltine *Chironomus* population in a Wisconsin bog lake. J. N. Am. Benthol. Soc. 9(2):180-192.

Coffman, W.P. 1984. Chironomidae, pp. 551-552. In: R.W. Merritt and K.W. Cummins [eds.], An introduction to the aquatic insects of North America. Kendall/Hunt, Dubuque.

Hellenthal, R.A. 1982. Using aquatic insects for the evaluation of freshwater communities. Pages 347-345 In: Armantrout, N.B. (Ed.). 1982. Utilization of aquatic habitat inventory information: Proceedings of a symposium held 28-30 Oct. 1981, Portland, OR.

Hilsonhoff, W.L. 1987. An improved biotic index of organic stream pollution. Grt. Lakes Ent.. 20(1):41-45.

Hilsonhoff, W.L. Rapid field assessment of organic pollution with a family-level biotic index. J. N. Am. Benthol. Soc. 7(1):65-68.

Johnson, R.K. and T. Wiederholm. 1989. Classification and ordination of profundal macroinvertebrate communities in nutrient poor, oligo-mesohumic lakes in relation to environmental data. Freshw. Biol. 21:375-386.

Lubchenco, J; Olson, AM; Brubaker, LB; Carpenter, SR; Holland, MM; Hubbell, SP; Levin, SA; MacMahan, JA; Matson, PA; Melillo,JM; Mooney, HA; Peterson, CH; Pulliam, HR; Real, LA; Tegal, PJ; Risser, PG; 1991. The sustainable biosphere initiative: an ecological research agenda. Ecol. 72:371-412.

Rosenberg, D.M. 1992. Freshwater biomonitoring and Chironomidae. Neth. J. Aquat. Ecol. 26:101-122.

Rosenberg, D.M. and V.H. Resh. [eds.]. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York.

Ryding, S.O. and W. Rast. 1989. The control of eutrophication of lakes and reservoirs. Casterton Halt, Carnforth.

Saether, O.A. 1979. Chironomid communities as water quality indicators. Holarct. Ecol. 2:65-74.

Schindler, D.W. 1987. Detecting ecosystem responses to an anthropogenic stress. Can. J. Fish. Aquat. Sci. 44(Supp. 1):6-25.

Thienemann, A. 1922. Die beiden Chironomusarten der tiefenfauna der norddeutschen seen. ein hyrobiologisches. Problem.Arch. Hydrobiol. 13:609-646.

Ward, J.V. 1992. Aquatic insect ecology. John Wiley & Sons, Inc.,New York.

Welch, P.S. 1952. Limnology. McGraw-Hill, New York.

Wetzel, R.H.1983.Limnology. Saunder College Publishing, Philadelphia.

Wiederholm, T. 1977. Benthos of an acid lake. Oikos. 29:261-267.

Wiederholm, T. 1980. Chironomids as indicators of water quality in Swedish lakes. Acta Univ. Carol. Biol. 1978:274-283.