

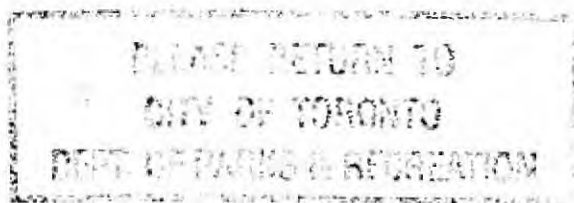
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High Park

Local History



THE COMPARATIVE LIMNOLOGY OF GRENADIER AND CATFISH (WEST) PONDS, HIGH PARK, TORONTO, ONTARIO

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EXECUTIVE SUMMARY

This report presents the comparative limnology of Grenadier and Catfish ponds, High Park, Toronto, Ontario; and, where possible presents comparisons between our 1983 study and the last comprehensive study of Grenadier Pond undertaken by Wainio *et al.* in 1976. It is our intention to provide benchmark data for future comparative studies.

Our major findings are:

1.0 PHYSICOCHEMISTRY

- 1.1 Grenadier and Catfish ponds are highly eutrophic, culturally impacted systems. The chemistry of both ponds is heavily influenced by sodium and chloride presumably derived from road salting. Sodium and Chloride now comprise an average of 58% and 43% respectively of major cation and anion equivalences as compared to 16% in Lake Ontario and 5% in smaller inland lakes (Section 5.8.2.).
- 1.2 The effects of salting are more severe in Catfish due to its morphometry (Section 4.2.) and the system is now meromictic (permanently chemically stratified) (Section 5.1.3.) The monimolimnion of Catfish is anaerobic and highly reduced with increased concentrations of almost all elements (Section 5.8.).
- 1.3 Water quality in Grenadier, as defined by water transparency, has improved substantially since 1976. Secchi depths now extend to over 4m as compared to less than 1m in 1976 (Section 5.7.4.). Zooplankton species composition points to improved water transparency (Section 6.4.2.). Oxygen concentrations are higher in the epilimnion of Grenadier than they were in 1976. Lower waters still go anaerobic, however oxygen remains there approximately a month longer than in 1976 (Section 5.3.2.). Changes in pH also suggest decreased amounts of photosynthesis and decomposition over 1976 (Section 5.4.1.).
- 1.4 Water quality is poor in Catfish. Secchi depth averages 0.6 m (Section 5.7.2). The lower portion of the freely circulating zone of the pond (> 2.5 m) was already low in oxygen by the first sampling (4 April, 1983). There was no oxygen below 1.5 m by 4 July (Section 5.3.3).
- 1.5 Of the suite of heavy metals analyzed, only copper exceeds the published Ministry guideline ($0.5 \text{ mg}\cdot\text{m}^{-3}$), $14.5 \text{ mg}\cdot\text{m}^{-3}$ in Grenadier, $9.0 \text{ mg}\cdot\text{m}^{-3}$ in the Catfish mixolimnion and $27.0 \text{ mg}\cdot\text{m}^{-3}$ in the Catfish monimolimnion. We feel additional testing is warranted to evaluate sources of copper loading (Section 5.8.3.).
- 1.6 Potassium is highly elevated in Catfish. We have no explanation for the source of K^+ loading but recommend further testing for any potentially toxic counter ion (*e.g.* cyanide, Section 5.8.2.).
- 1.7. Of the suite of organo-contaminants analyzed none were above the limits of detection of the technique (Section 5.8.4.3).
- 1.8 Alternate week sampling provided the same information (mean and standard deviation) as weekly sampling (Section 5.8.).
- 1.9 We find little evidence to support the 1976 observation that Grenadier is "frequently" polymictic. Mixing regimes have implications for water column temperatures, oxygen concentrations and chemistry. As such they impact on strategies for either species or nutrient management. The polymixis observed in 1976 was associated with unusually warm summer conditions; neither it nor they have reoccurred since 1976 (Section 5.2.2.).

2.0 BACTERIOLOGICAL WATER QUALITY

- 2.1 Only Catfish represents a "potential health hazard" with fecal coliform geometric mean densities in excess of 100 cells per 100mL (Section 5.9.1.).
- 2.2 FC/FS (Fecal coliform/Fecal streptococcus) ratios fall between 4 and 0.7 and are inconclusive as to the contamination source (Section 5.9.1.).
- 2.3 There is a significant ($p < .01$) relationship between daily rainfall and fecal coliform counts at the north end of Grenadier (Station B) (Section 5.9.2.).

3.0 PLANKTON PROCESSES

- 3.1 It was not possible to determine whether nitrogen or phosphorus was the limiting nutrient in either pond (Section 5.8.2.).
- 3.2 Phytoplankton biomass as either chlorophyll or wet weight biomass is significantly higher in Catfish over Grenadier (Section 6.3.).
- 3.3 Zooplankton biomass and fecundity are higher in Grenadier than in Catfish. Grenadier is dominated first by Cladocera then by Copepoda. Catfish is consistently dominated by Cladocera (Section 6.4.).
- 3.4 *Daphnia parvula* has replaced *D. rosea* in Grenadier since 1976 and *Diaphanosoma sp.* has disappeared. These species shifts are consistent with improved water clarity, subsequent increases in predation pressure from visual predators and increasing competition among zooplanktors for food (Section 6.4. and 6.5.).
- 3.5 Energy flow patterns are quite dicotomous between the two ponds. Density regulation mechanisms for plankton appear to be nutrient based (*i.e.* nitrogen and/or phosphorous) in Catfish, but biologically based (*i.e.* zooplankton grazing) in Grenadier. We suggest that differences in fish community are responsible but do ^{not} have adequate data to test the hypothesis (Section 6.5.).

4.0 WATERSHED-MARSH OBSERVATIONS

- 4.1 Vegetated marshland in Grenadier analyzed from airphotos reveals little change overall since 1976. The north end of the marsh has expanded slightly southward.
- 4.2 There are no obvious changes in land use in the watershed suggestive of increased erosion, *etc.*, that would suggest allochthonous based infilling is occurring in Grenadier (Section 2.3.).
- 4.3 Construction of the settling pond on the north inflow to Grenadier appears to have created an expanding subsurface sediment wedge in the north end of Grenadier Pond itself, just below the marsh (Section 2.3.1).
- 4.4 We suggest that the agreement between an Areal Hypolimnetic Oxygen Deficit (AHOD) model and calculated AHOD's in Grenadier is evidence that the majority of production in the system is autochthonous (Section 6.1.3.).
- 4.5 Airphoto analyses for Catfish reveals a pattern similar to that noted by Wainio *et al.*, 1976, in Grenadier: Gross reduction in peripheral marsh over the last 40 years with only traces of marsh remaining at the north end of Catfish (Section 2.3.2.).

RECOMMENDATIONS FOR FURTHER STUDY

Seven (7) specific points should be addressed if any chemical/nutrient/species management strategies are to be implemented for either Catfish or Grenadier:

1. The ponds should be extensively re-monitored at approximately 8-10 year intervals.
2. Additional sampling is necessary to determine sources of high copper concentrations in both ponds.
3. Additional sampling in Catfish is warranted to establish presence/absence of potentially toxic potassium counter ions (e.g. cyanide) and to determine sources if found.
4. Additional sampling is necessary to determine the pattern of nutrient limitation in each pond (i.e. tissue analyses, laboratory and/or field limnocorral nutrient manipulation).
5. Additional sampling should be undertaken to determine more detailed population dynamics of phytoplankton and zooplankton in the two ponds.
6. Non-removal based, detailed enumeration (e.g. electrofishing) of the fish community, species, and growth rates is necessary to evaluate the extremely dicotomous patterns of energy flow between the two ponds.
7. Any potentially beneficial effects from increased ionic strength (Na/Cl) on metabolic costs of organisms should be evaluated.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Grenadier and Catfish ponds are located in the southwest corner of Metropolitan Toronto, one kilometer northwest of the outflow of the Humber river into Lake Ontario (43 38' Lat., 79 28' Long., Figure 1.1.). In the mid 1930s Grenadier pond (12.7 Ha) was fully incorporated into the recreational area of High Park. Catfish (1.1 Ha), or West Pond as it is also known, was incorporated into Rennie park in the mid 1960s. Since the 1930s, High Park has been considerably altered by the construction of a number of recreational facilities. Concomitant with these changes both ponds have seen increasing recreational use.

The only previous limnological survey of Grenadier Pond, by Wainio *et al.* (1976), included data from as early as 1964 and concluded that Grenadier pond was highly eutrophic and supported a large warmwater fishery. The survey also included a history of the pond since its separation from Lake Ontario by establishment of a permanent sandbar. Since 1978, Grenadier and Catfish ponds have been surveyed annually, during September and October, by limnology classes (ZOO471) at the University of Toronto. Analyses of these data, a collection and analyses of a summer series of data, and comparison to the data in Wainio *et al.* (1976) comprise this report.

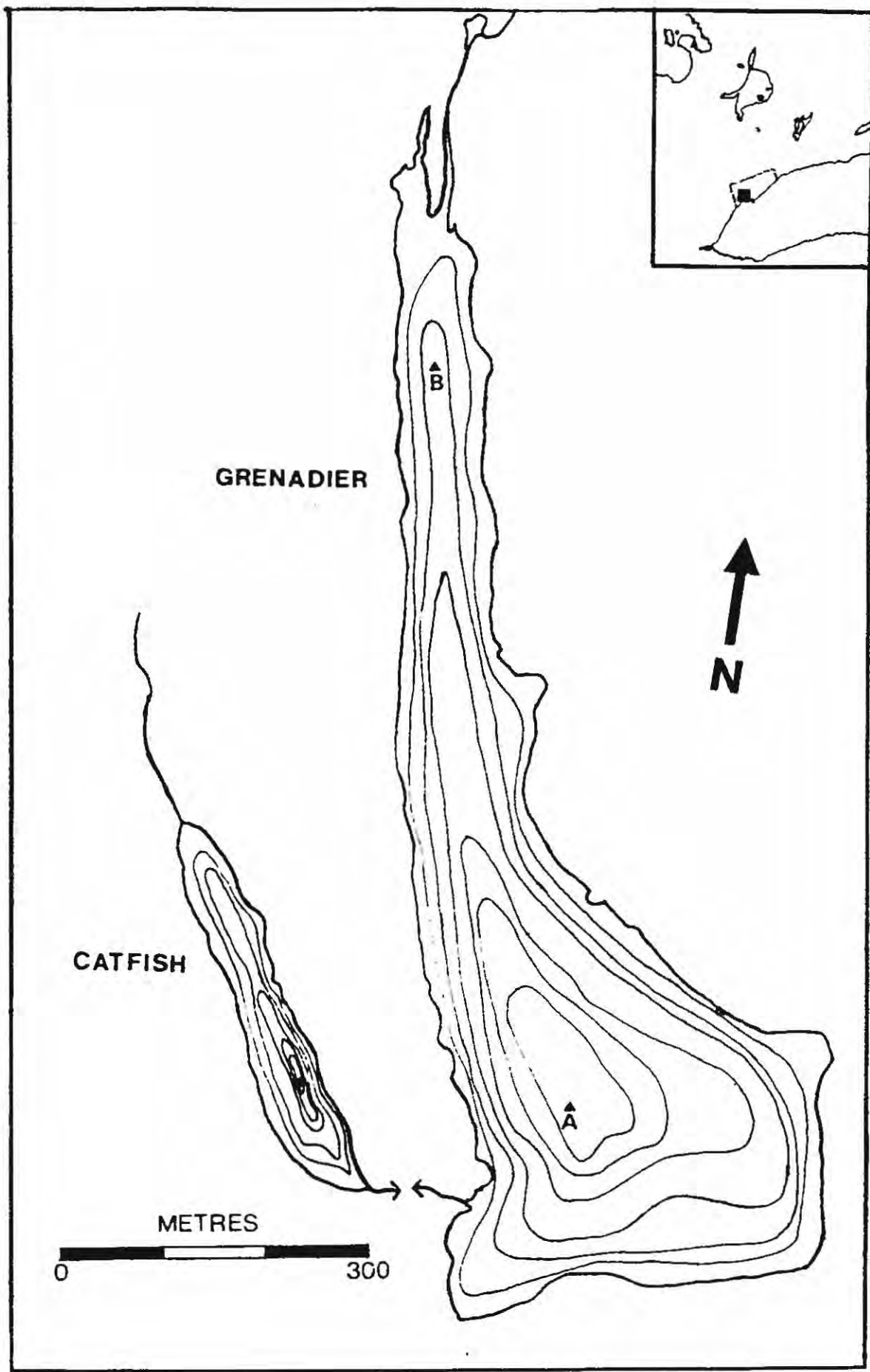


Figure 1.1. Geographic location and bathymetry of Grenadier and Catfish ponds.

2. HISTORICAL BACKGROUND

2.1. Geological Origins

The formation of Grenadier and Catfish ponds is rooted in the retreat of the Ontario lobe of the Wisconsin ice sheet, 12,000 years BP (Karrow *et al.*, 1961). Proglacial Lake Iroquois, formed in the Lake Ontario basin south of the retreating Port Huron ice, exceeded Lake Ontario in depth by 35.05 meters (Karrow *et al.*, 1961). Its shoreline extended 8 kilometers up the present Humber valley (Chapman and Putnam, 1966). Detritus, transported by rivers and streams, was deposited as soft deltaic sediments of sand, silt and gravel in the Humber Bay of Lake Iroquois (Chapman and Putnam, 1966; Coleman, 1933). Partial retreat of the ice sheet from Covey Hill New York, opened a lower drainage channel for Lake Iroquois, south to the Hudson river. This low water stage was the relatively short-lived Lake Frontenac, which in turn was followed by Lake Fort Ann when the continued retreat of the ice from the Covey Hill area caused a further drop in lake level.

The Lake Fort Ann stage lasted until drainage shifted from the Hudson to the St. Lawrence valley, subsequent to the breakup of the St. Lawrence ice block (Chapman and Putnam, 1966). Lacustrine sediments, deposited under high water conditions were exposed during the low water stages of Lakes Frontenac and Fort Ann. Fluvial processes subsequently eroded these deposits into steep-sided ravines and valleys. As the ice retreated further northwards, the St. Lawrence valley area uplifted (isostatic rebound), raising the water level in Lake Fort Ann and flooding those valleys formed in the preceding stage. Grenadier and Catfish ponds presumably formed as a result of the build up of barrier bars of sand and gravel across the mouths of these flooded stream valleys (Coleman, 1933).

2.2. Recorded History: Nineteenth Century

2.2.1. Grenadier Pond

Bondhead's observation of a miry little spot represents the first recorded observation of Grenadier Pond. The pond's name appears to originate from some possibly apocryphal instance involving the Grenadier company of The King's 8th regiment, which was temporarily stationed at Fort York at the time of the American invasion of York in April of 1812 (Finan, 1964). According to Sir Francis a party of guardsmen were attempting to cross the pond in a boat. They capsized, floundered in the mud, sank and "...were there still" (Sir Francis Bondhead in Lizars, 1913: page 54). A second legend links the origin of Grenadier's name to an incident one winter when a regimental guardsman drowned after falling through the ice (West, 1967: page 171).

Little else is recorded of Grenadier pond until 1836 when J.G. Howard, York's first city surveyor, purchased lot 37 from Mr. James Cull (McManus, 1975). Lot 37 consisted of 165 acres of land reaching from Bloor street, south down to the Humber bay lakeshore, encompassing the southeast portion of Grenadier pond. Over the next 40 years Howard cleared and farmed some of the land and built a residence, Colborne Lodge (McManus, 1975) - which is still standing, maintained by the Historical Board of Toronto.

In 1873, for a yearly stipend of \$1200 the Howards donated lot 37 to the City of Toronto. Among other stipulations, the Howards requested that the land be named High Park and be kept as a recreational area for the citizens of Toronto. The remainder of Grenadier pond was incorporated into High Park as the City of Toronto acquired adjacent lands: 71 acres in 1930, 36 of which were pond, were purchased by the city from the Chapman estate (pers. com., City of Toronto, Department of Parks and Recreation); in 1967 a final 2 acres, encompassing the remainder of the pond's west shore, were acquired when the village of Swansea was annexed by the city of Toronto (pers. com., City of Toronto, Department of Parks and Recreation).

2.2.2. Catfish Pond

Far less is known of the early history of Catfish pond. From an early map of the area (surveyed and drawn by J.G.Howard in 1869) it appears that Catfish was a deep hole in a marshy stream more than it was a pond. The map indicates that the "pond" was bordered on the south by an extensive marshy area and flowed via two distributaries into Grenadier pond. A cart track ran between the two ponds, northward to the residence of Juno Ellis. The draining of the southern marsh and impoundment of Catfish pond most likely occurred during the late 1800's when the village of Swansea constructed Ellis avenue along the route of the old cart track.

2.3. Twentieth Century

2.3.1. Grenadier Pond

Extensive changes have occurred in the watersheds of Catfish and Grenadier ponds concomitant with development in western Toronto. Wainio *et al.* (1976) analyzed the 1:50000 series airphotos from 1947 (the start of the series) and found that there had been a progressive loss of marsh from the perimeter of the pond. In most locations the loss has been complete, and is probably due to the extensive infilling and bank construction which has taken place over the last 30 years. In particular 1955 and 1956 saw 11 acres of the southern part of the pond filled in by the construction of the Queen Street West extension (Wainio *et al.*, 1976). Between 1953 and 1959 the High Park grounds were extensively developed: tennis courts, swimming pool and the hillside gardens were all constructed. By the early 1970's only two of the original marsh areas still existed and these were severely reduced in area: one, in the southwest corner of the pond, brackets the inflow from Catfish pond; the other, at the north end, borders the main Grenadier inflow. Concomitant with the reduction in marshland was an extensive loss of natural bankside: 45% of Grenadier's perimeter is presently contained behind concrete

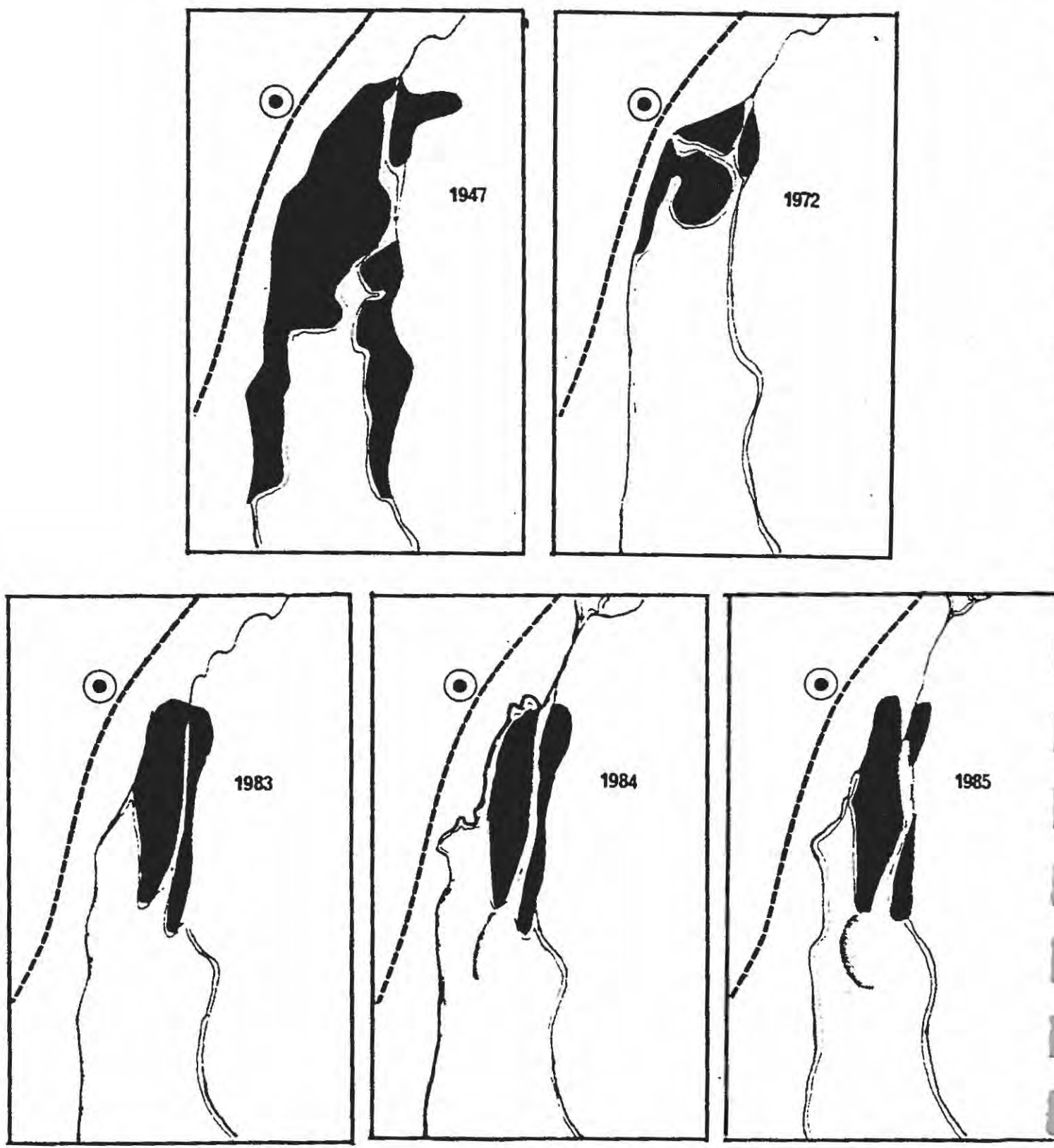


Figure 2.3.1. Changes in Marsh area in Grenadier pond's north end from 1947 to 1985.
The light hatched areas shown on the 1984-85 maps represent a subsurface sediment wedge.

embankments. Only the western shore between and including the two extant marshes retains its natural riparian cover and remains free of artificial embankments.

An analysis of the air photos subsequent to the Wainio study of 1976 show two changes in Grenadier. The vegetated marsh appears to have expanded slightly since the 1972 air photo (Figure 2.3.1). In addition, a small pond was constructed 150 meters north of Grenadier on the inflow stream in the summer of 1983. This sediment settling pond was constructed in response to the concerns voiced by local pond watchers that the north end of Grenadier was rapidly filling in. It seems somewhat unlikely that the sediment loads delivered to the north end of Grenadier are currently much higher than twenty years ago. Most of the watershed drained by the north inflow is from an urban area established in the late 1800s/early 1900s and there is little evidence of recent watershed changes likely to have evoked increased erosion. However, since construction of the settling pond, a sub-surface sediment wedge has appeared south of the extant marsh, Figure 2.3.1. Comparison of the 1984 and 1985 air photo suggest that this wedge is increasing in size. Evaluation of the settling ponds effect on the north end marsh should be undertaken.

2.3.2. Catfish Pond

Like Grenadier Pond, Catfish has experienced a gross reduction in peripheral marsh over the last 40 years. In 1947 two sections of marsh were evident: the smaller, at the south end of the pond near the outflow; the larger at the north end near the inflow stream. The development of houses during the mid 1950's adjacent to the south and southwest margins of Catfish undoubtedly contributed to the extinction of the southern marsh. While traces of the northern marsh are still present today the bulk of the marsh appears to have disappeared during the landscaping of Rennie park.

Concrete embankments are a recent addition to Catfish pond, having been installed along the park section of the southeast shore in 1982, apparently in response to erosion caused by heavy foot traffic. Public access to Catfish is limited as private lots abut the south, southwest and

part of the southeast portions of the pond. The mid-western shore of the pond is separated from Coehill Drive by a steep, narrow grade. The mid eastern shore is blocked by a heavily wooded steep grade, although there are a few footpaths evident on both shores.

4. WATERSHED CHARACTERISTICS

Grenadier Pond drains 283 hectares of land of both an urban (74%) and developed parkland (26%) nature (Elstad, 1983). Catfish Pond, incorporated within Grenadier Pond's drainage basin, is 52 Hectares in size and is composed of urban (87%) and developed parkland (13%) sections (Elstad, 1983).

4.1. Drainage

Catfish Pond has two main inflows: one, taking runoff from Rennie Park and storm sewer drainage from the north, enters the Pond by way of a channeled stream at the Pond's north end; the second carries flow from the Coehill Drive storm sewer (Elstad, 1983) and enters the Pond by way of a pipe halfway up the Pond's western margin. The outflow from Catfish is in the southeast corner of the Pond and drains via a pipe and ditch into Grenadier Pond.

Grenadier has 2 inflows: the main one being a stream entering the Pond through the marsh at the north end. This stream receives runoff from the northwest quadrant of High Park and flow from the storm sewers outfalling at Clendenan Avenue, Bloor, Valleymede and Ellis Park roads. The next major inflow, enters the Pond at the marsh located in the southwest corner of the pond and carries flow from Catfish and the Ellis Avenue storm sewer. Grenadier Pond empties through a weir in the southwest corner of the pond, via a sewer, into Lake Ontario. The Steel Company of Canada (STELCO) possesses riparian rights to the water flowing from Grenadier and can affect flow depending on need (Stelco engineer, pers. com.: In Wainio *et al.*, 1976).

While both ponds receive a large portion of their inflow from urban runoff, the relative quality/quantity of urban inputs may not be the same: The storm sewer system servicing Catfish pond's watershed was constructed by the village of Swansea in the mid 1900s and was

designed to carry runoff from both the streets and residential rooftops; Grenadier's urban area is older and has a storm sewer system which, theoretically, drains only road runoff, building runoff being routed through sanitary sewers. (Whichman, pers. com.: In Elstad, 1982).

4.2. Pond Morphometry

Grenadier and Catfish ponds lie within the confines of adjacent, steep sided valleys (Section 2.1.). Both ponds are shallow. Grenadier, is the larger more exposed system with a 9 times larger area and a 15 times greater volume (Table 4.2.1). Most of the other morphometric parameters are derived from these original differences in size and are generally within expected ranges (Hutchinson 1975, Wetzel 1983). The z/z_{\max} ratio in Catfish is an exception which has important physico-chemical implications for the chemistry of the system.

Table 4.2.1.: Grenadier and Catfish Pond Morphometry

Variable	Symbol	Grenadier	Catfish
Area (Ha)	A_0	18.9	2.04
Volume ($m^3 \times 10^5$)	V^0	5.52	0.345
Maximum depth (m)	Z_{\max}	6.5	5.5
Mean depth (m)	\bar{z}	2.9	1.7
Mean depth/Max. depth	\bar{z}/z_{\max}	0.4	0.3
Relative depth (%)	Z_{\max}	1.3	3.4
Littoral zone (%)	LITT	26.8	28.7
Fetch (km)	F	1.140	0.406
Compass orientation ($^{\circ}$ N)	C_0	340.7	293.7
Perimeter (km)	P	2.9	0.88
Shoreline development	D_L	1.88	1.73
Flushing rate ($yr.^{-1}$)	f	2.76	7.59

z/z_{\max} is a comparable variable to the ratio of a lake's actual volume to the volume of a cone of equal surface area (A_0) and height (z_{\max}). Theoretical and analytical evaluation of such ratios suggest that the z/z_{\max} ratio ranges between 0.33 and 0.5 with an average of 0.46 for lakes with only minor irregularities in bottom topography. (Wetzel, 1983). Lakes with ratios > 0.5 are extremely steep-sided, deep, fjord type lakes. A ratio of < 0.33 is indicative of a lake with a deep hole or some other extreme deviation in bottom topography (Hutchinson, 1975).

The z/z_{\max} of 0.30 in Catfish derives from a relatively deep hole (Figure 1.1.). This morphometric quirk in combination with the greater degree of fetch protection afforded Catfish by its high banks and built-up perimeter acts to reduce wind driven turbulent mixing. In our opinion, this reduction in mixing and high anthropogenic salt loads are the basis for the meromixis exhibited by Catfish Pond (Section 5.1.3.).

Percent littoral zone (LITT) is the only other morphometric variable that may appear out of line given the shallow nature of the two ponds. Our determination of LITT is based on the % of sediment area to which 10% incident light penetrates. In this case LITT values for both ponds were calculated using transparency values averaged over the 11 collecting cycles. The low values of LITT are directly attributable to low water transparency in these highly eutrophied systems.

5. PHYSICO-CHEMISTRY

5.1. General Discussion

5.1.1. Grenadier Pond

Mean summer hydrolab parameters for Grenadier (temperature, dissolved oxygen, pH, conductivity and oxidation-reduction potential or pE) are presented in Figure 5.1.1. In general they are what would be expected for a shallow, eutrophic system. Thermal profile development is weak (Section 5.2.1.). Oxygen values are high in the upper waters and fall off towards anoxia (Section 5.3.1.). pH mirrors oxygen with higher values in the upper waters reflecting photosynthetic activity and lower values in the lower waters where respiratory processes dominate (Section 5.4.1.). Conductivity is reasonably uniform in the upper waters and increases closer to the sediments, probably reflecting diagenetic release from accumulated materials and/or release of materials from the sediments (Section 5.5.1.). Oxidation-reduction potential or pE follows dissolved oxygen and pH with high positive values indicative of oxidizing conditions in the surface waters and low negative values indicative of reducing conditions in the lower waters (Section 5.6.1.). Raw data for Site A and B can be found in Appendix 1.

5.1.2. Catfish Pond

Mean summer hydrolab parameters for Catfish Pond are presented in Figure 5.1.2. In most respects, they appear similar to the Hydrolab parameters for Grenadier and again are reasonably characteristic of a shallow eutrophic system. Thermal profile development (Section 5.2.2.) appears stronger in Catfish than Grenadier (*i.e.* a better developed "hypolimnion"), but thermal conditions actually result from the meromictic nature of the pond (Section 5.1.3.).

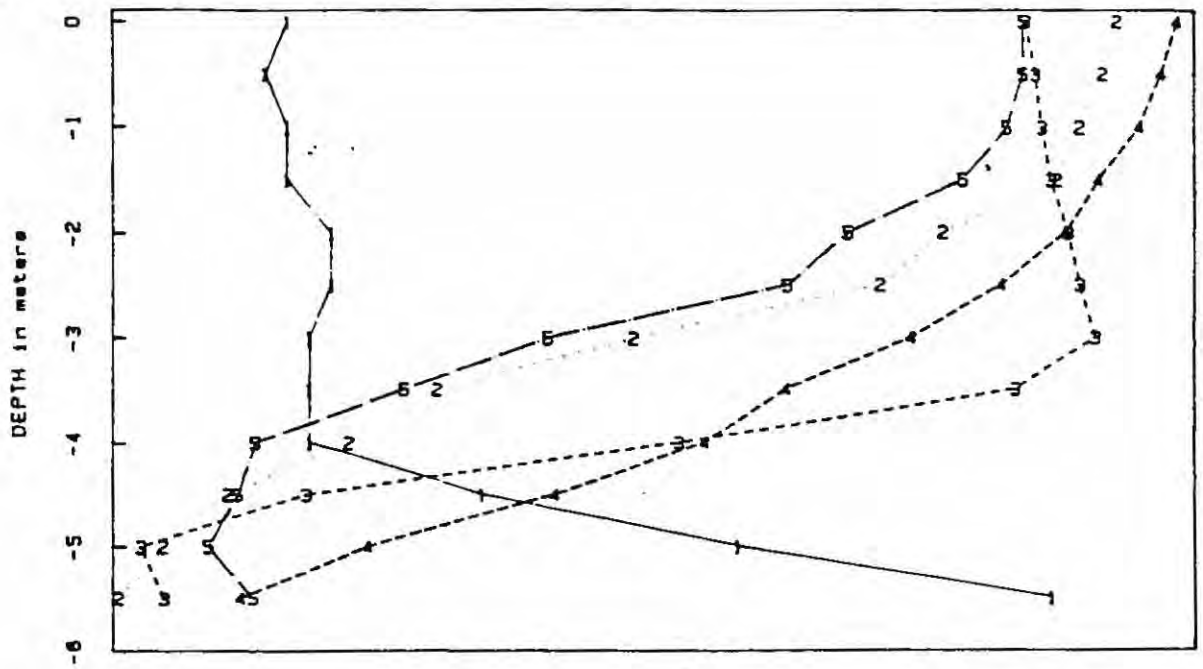


Figure 5.1.1. Grenadier station A: Mean summer hydrolab values.
 1 = Conductivity, 2 = Dissolved Oxygen, 3 = ORP, 4 = Temperature, 5 = pH

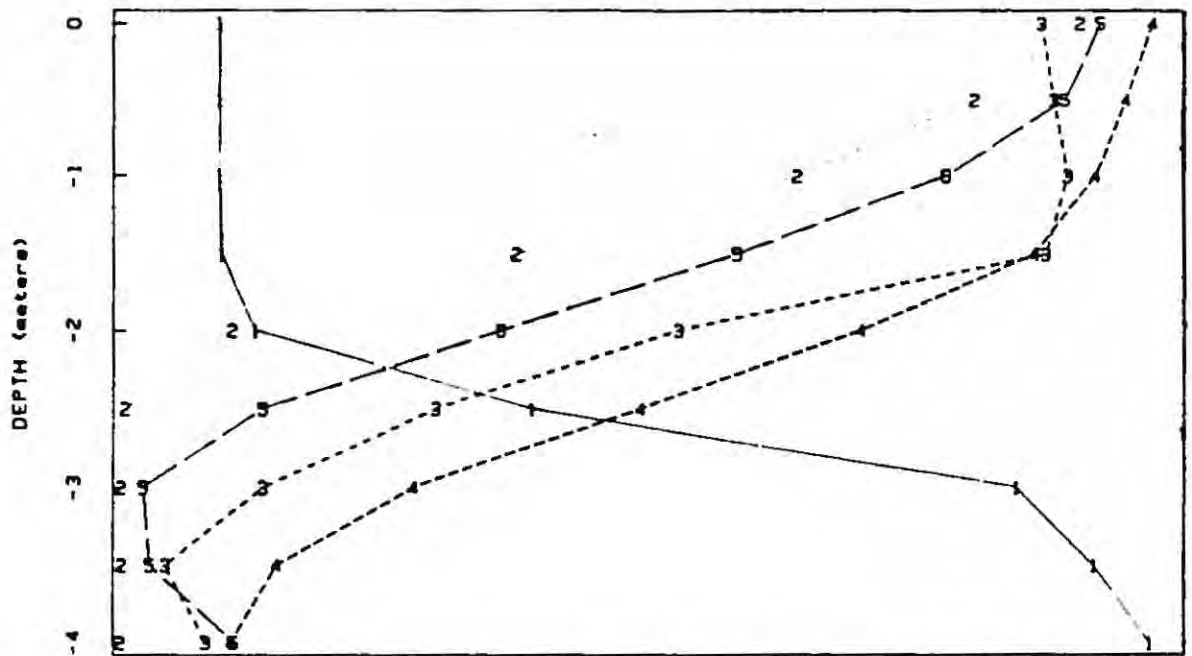


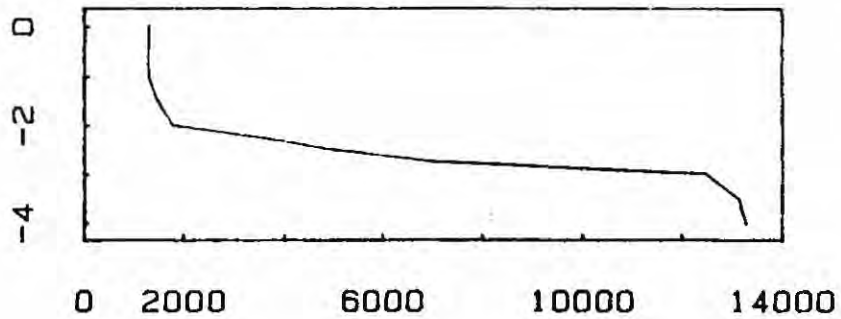
Figure 5.1.2. Catfish pond: Mean summer hydrolab values.
 1 = Conductivity, 2 = Dissolved Oxygen, 3 = ORP, 4 = Temperature, 5 = pH

Additionally, in Grenadier all three parameters (DO, pH, pE) show their most abrupt changes in slope at 4 meters (the depth at which the "thermocline" occurs or more precisely, the depth at which the slope of the second derivative of the decline in temperature with respect to depth is 0). In Catfish the depth at which these three parameters make their most abrupt change in slope is 2 metres, almost a metre above the "thermocline". This later slope break is coincident with the second derivative defined inflection point in the conductivity profile or chemocline. The above observations constitute the majority of the evidence that Catfish is a chemically stratified system rather than a thermally stratified system and is therefore meromictic rather than dimictic or polymictic as was Grenadier. Meromixis confers a new terminology. Rather than referring to thermally defined regions in a meromictic lake (*i.e.* epi-, meta- and hypolimnia) the upper circulating portion is called the mixolimnion, the lower non-circulating portion the monimolimnion. The two regions are separated by the chemocline.

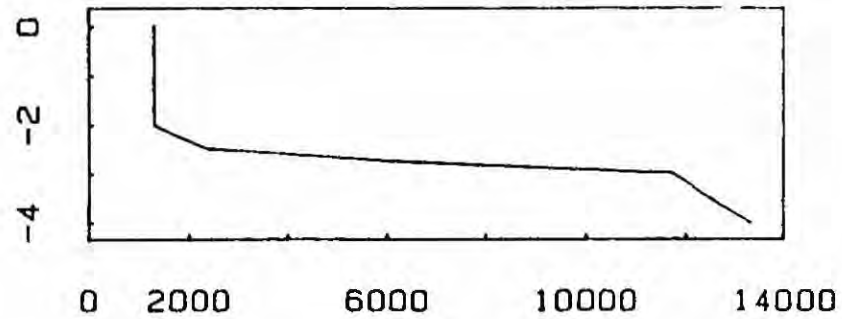
We believe that meromixis in Catfish pond is due to high anthropogenic salt loadings combined with unusual morphology and bank geography (see Section 5.5., Conductivity, and details of watershed-pond morphology in Section 4.2. Pond Morphometry). Salt loading has been shown to cause at least temporary meromixis in a lake (Judd, 1970). We are not aware of any other reports of road-salt associated ectogenic meromixis, however evidence of anthropogenically induced meromixis resulting from clear-cutting exist in the paleolimnological record (Frey, 1955). We are not sure exactly when Catfish became meromictic. Figure 5.1.3. presents selected conductivity profiles from 1978/1979 and clearly shows that the pond was chemically stratified as early as 1978. Pollen stratigraphy (Galvin, 1981) and metal analyses (Ramcharan, 1980) from Catfish sediment cores suggest major changes in sediment chemical composition patterns occurred about 24 cm into the core. This depth occurs above noted sedimentary effects of Hurricane Hazel in 1954 (estimated at 35 cm) and suggests that Catfish probably became meromictic in the late 60's (Galvin 1981).

Conductivity measurements taken over the past 7 years show that the chemocline has remained reasonably stable, with significant increases in conductivity beginning at about 2-2.5

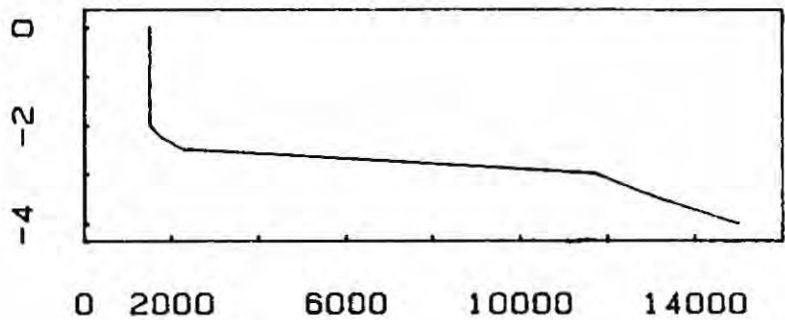
Sept. 19



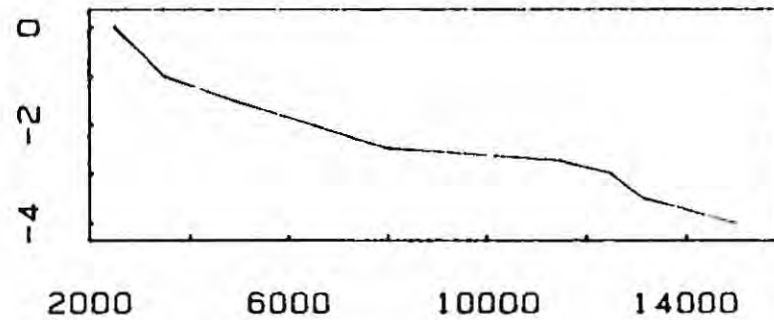
Oct. 10



Nov. 7



Feb. 6



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Figure 5.1.3. Conductivity profiles for Catfish pond (1978-79).
Y axes = depth (m), X axes = conductivity (umhos/cm).

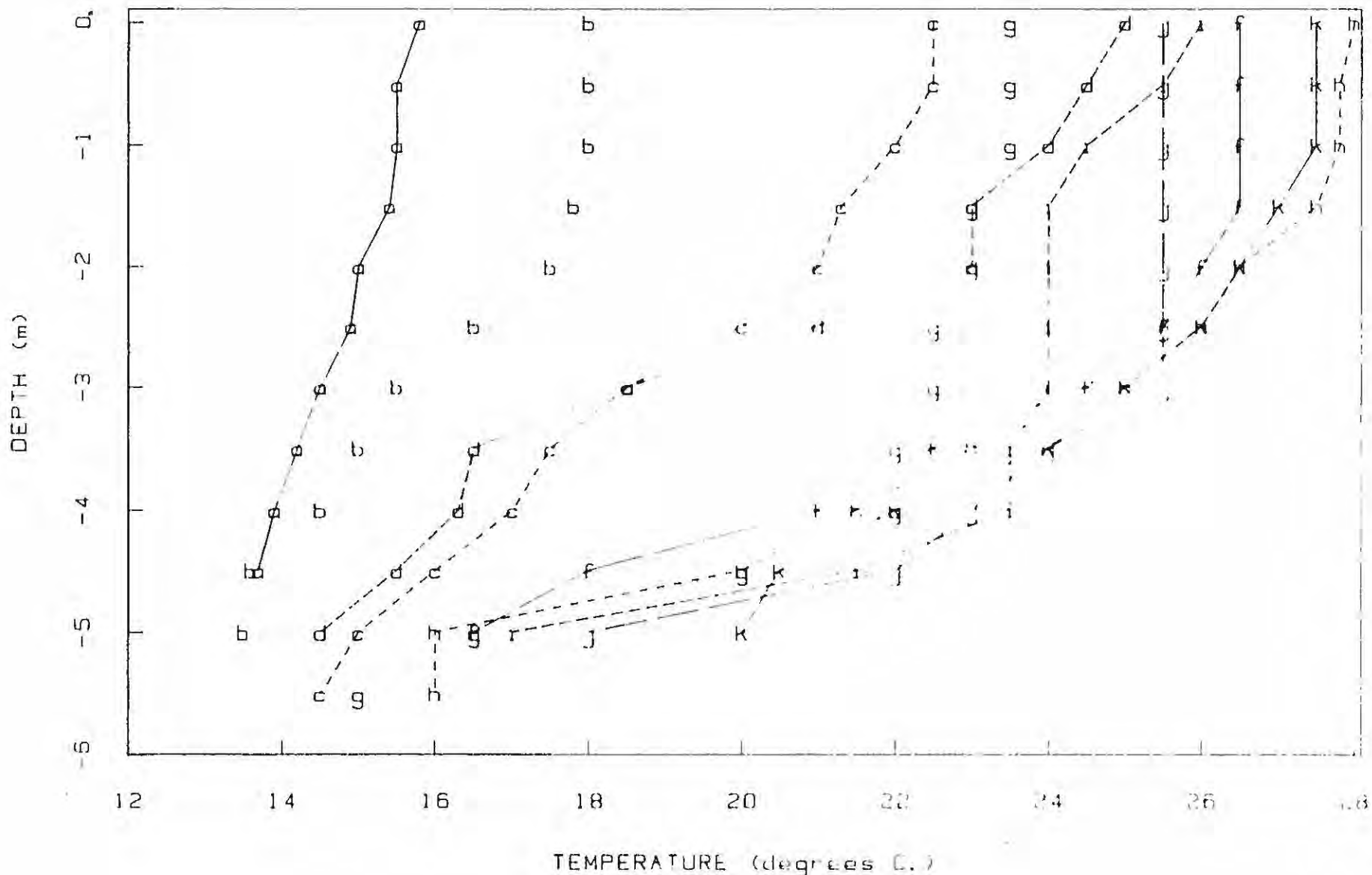
m. The 1978 - 1979 conductivity profiles indicate that chemical stratification also remains reasonably constant over the ice-free period of the year and probably reflects some sort of meta-stable equilibrium. Under-ice the situation appears to be much more non-equilibrium. The February 6th profile (Figure 5.1.3.) suggests that meltwater entering in the winter, while salt-laden, is probably less dense than the monimolimnion and flows along the top of that layer towards the outfall of the pond, gradually entraining mixolimnetic water. We believe that the shape of the conductivity curve under ice is fluid, its exact form at any given instant a function of the amount and specific density of the melt-water entering per unit time. After melt-water inputs cease, the system gradually settles back into its more normal, near-equilibrium state. In addition to the obvious reduction in the volume of water suitable for habitation by aerobic organisms, meromixis has implications for the chemical composition of both the monimolimnion and mixolimnion. These will be discussed in the sections to follow.

5.2. Temperature Specifics

5.2.1. Grenadier 1983

Grenadier Pond is not sufficiently deep ($z = 3.5$ m, $z_{\max} = 6$ m) for development of a complete thermal profile, i.e. there is no well developed hypolimnion, but the system does stratify into an epilimnion and what is best characterized as a metalimnion. Temperatures in Grenadier increased throughout the summer with minor fluctuations, Figure 5.2.1., and Appendix 1. The maximum recorded surface temperature, 28° C., was reached during cycle 8 (July 18th). Minor episodes of surface water cooling (cycles 7&9) are attributed to wind generated mixing. Concomitant depression of the epilimnion relative to previous, warmer cycles supports this contention.

The shallow site in Grenadier (Station B) is only 1.5 metres deep. Temperatures are more or less uniform throughout the column at site B with the maximum surface temperature reaching 28.5° C. on July 18, 1983 (cycle 8) Raw data for Site B are in Appendix 1.



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Figure 5.2.1. Depth-Temperature plot: Grenadier pond station A, summer 1983. Letters a-k represent sequential weekly samples.

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5.2.2. 1983-1976 (1966) Comparisons in Temperature

Earlier temperature profiles from 1976 (Wainio, *et al.*) are presented in Figure 5.2.2. and Appendix 3. Cycles 1 and 2 from 1983 bracket cycle 1 in 1976 (Table 5.2.1.).

Table 5.2.1.: Sampling Dates for Temperature Profiles for 1966, (Rigler) 1976, (Wainio *et al.*) and 1983 (Zimmerman *et al.*).

Cycle	DATE		
	1966	1976	1983
1	4 April	3 June	31 May
2	20 May	9 June	6 June
3	13 June	15 June	13 June
4	28 June	29 June	20 June
5	11 July	5 July	---
6	25 July	13 July	4 July
7	15 August	19 July	11 July
8	---	25 July	18 July
9	---	2 August	25 July
10	---	11 August	2 August
11	---	---	8 August

Despite the overlap of the sampling dates, Grenadier did not show well developed thermal stratification until cycle 3 (13 June) in 1983, and it was not until even later in the year that the thermal profile assumed its characteristic shape and the epilimnion is "usual" volume. The system was already well stratified by cycle 1 (3 June) in 1976. The differences in thermal profile development seem attributable to weather differences between the years. Not only was 1976 warmer than 1983 but it warmed earlier. Table 5.2.2. shows that there were only 160 heating degree days (HDD) below 18° C. in May of 1976 compared to 245 in 1983. In June of 1976 there were only 10.8 HDD compared to 45 in 1983.

Figure 5.2.3. shows temperature profiles for 1966 (Wainio *et al.* 1976 cf. Rigler 1966). The 1966 temperature profiles are similar to the those of 1983, with stratification not well established by cycle 2: 20 May, 1966 (Table 5.2.1.). HDD for 1966 show an even cooler spring than in 1983 with 496 HDD in May and 110 in June of 1966. Although the data are limited,

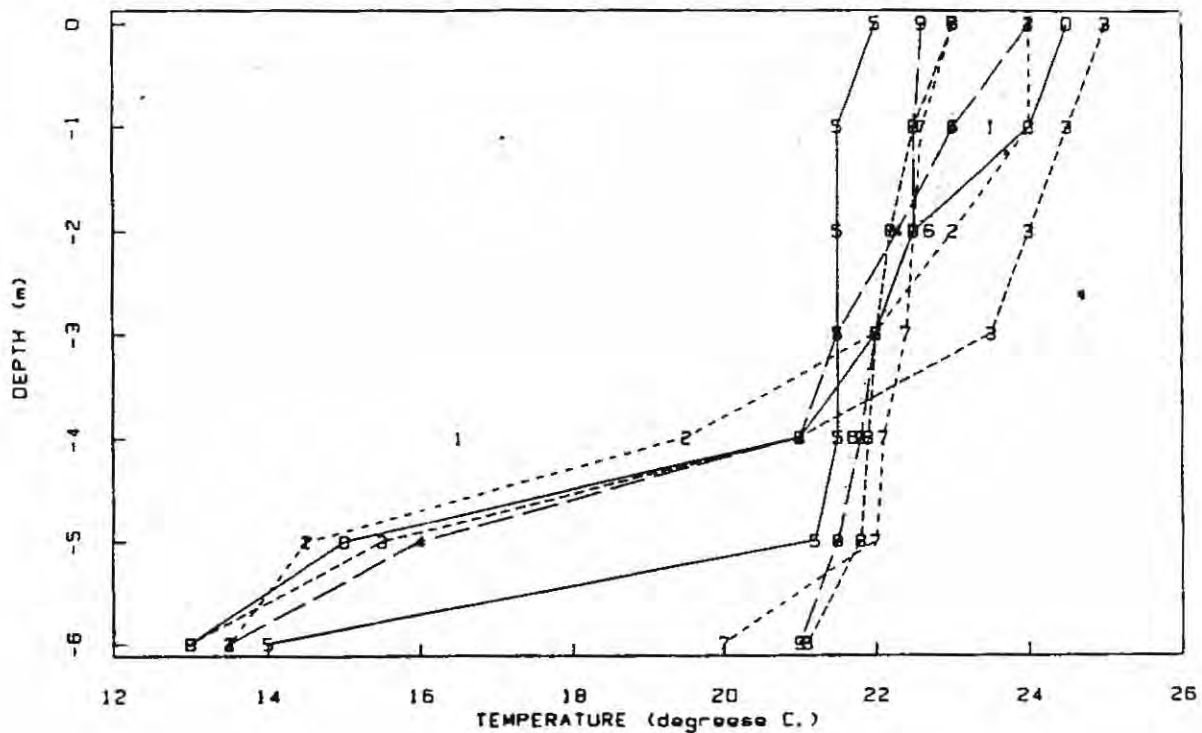


Figure 5.2.2. Depth-Temperature plot: Grenadier pond, summer 1976.
 0 = June 3, 1 = June 9, 2 = June 15, 3 = June 29, 4 = July 5,
 5 = July 13, 6 = July 19, 7 = July 25, 8 = August 8, 9 = August 11.

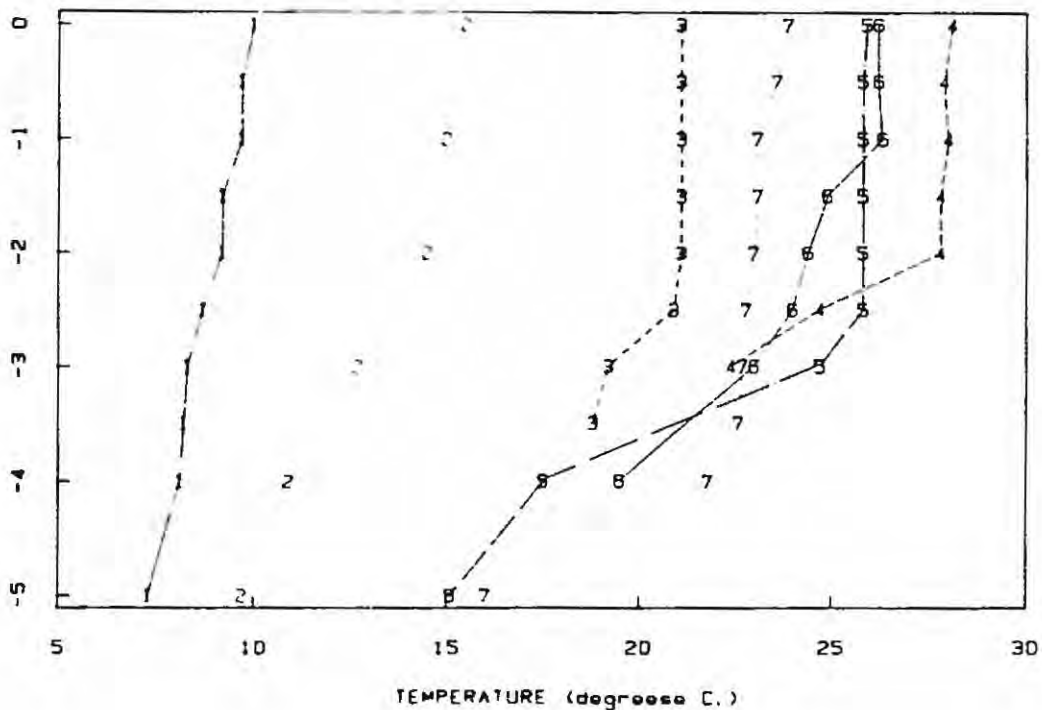


Figure 5.2.3. Depth-Temperature plot: Grenadier pond, summer 1966. Data from
 Rigler (in Wainio, 1976. Also see Appendix 3). 1 = April 4,
 2 = May 20, 3 = June 13, 4 = June 28, 5 = July 11, 6 = July 25, 7 = August 15.

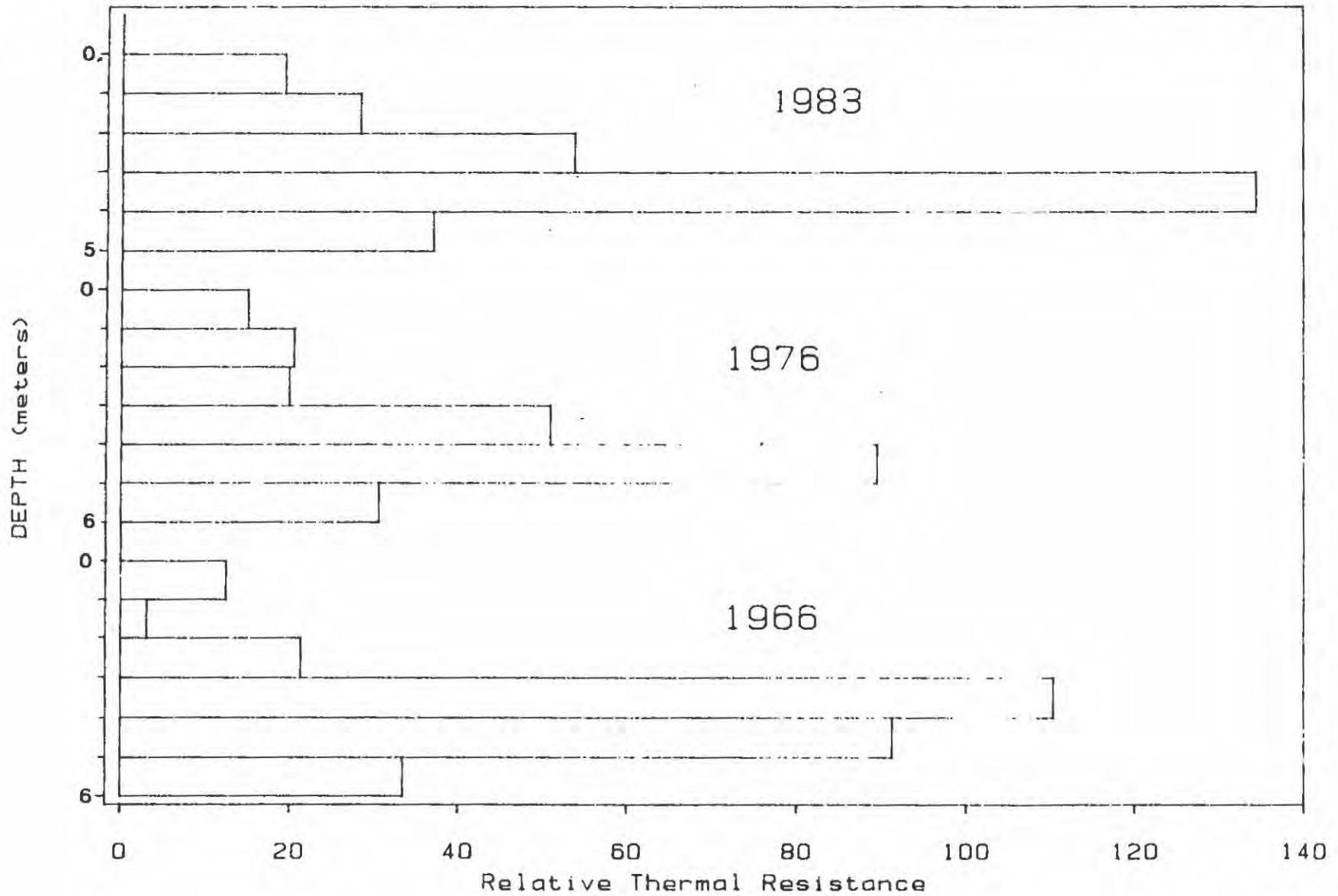
Table 5.2.2: Heating degree days below
18 ° C. for May through
August 1966, 1976 and 1983

Month	1966	1976	1983
May	496	160	246
June	110	11	45
July	5	2	8
August	40	13	8

it appears that the thermal profile is reasonably well developed by cycle 3 (13 June, 1966) even though surface waters are only about 20° C. as opposed to 24° C. in 1976 and 22° C. in 1983.

Although the general thermal patterns appear similar across the years, there was a complete mixing of the water column in 1976 (estimated as having occurred on 11 July, 1976-see cycle 6, Figure 5.2.2.) after which the bottom waters of the pond remained warmer and the surface waters somewhat cooler than in 1983. The exact cause of the turnover is not clear. Data on maximum and peak wind speed and direction are presented in Table 5.2.3. Neither maximum nor peak winds are substantially different across the years, although the prevailing wind in June of 1976 comes from the east. In comparison to other years and in consideration of "normal" weather patterns in the Toronto area, this prevailing easterly wind would seem unusual. Although the fetch in Grenadier is not oriented to the east, the easterly side of Grenadier is exposed and the south-east corner of the pond opens onto its deepest section. (See Section 4, particularly Table 4.2.1. Morphometry of Grenadier and Catfish Ponds and Figure 1.1. which details Grenadier bathymetry). Figure 5.2.4. shows relative thermal resistance (R.T.R.) to mixing in Grenadier for 1966, 1976, and 1983. We believe the warmer weather or a combination of the warmer weather and unusual wind direction of 1976 resulted in a thermal profile sufficiently reduced in R.T.R. to allow rather pedestrian wind speeds to effect turnover.

We think this combination of weather and wind somewhat unusual. Consequently, we can not agree with Wainio *et al.*'s, (1976, cf Rigler, pers. com.) contention that polymixis (summer turnover) in Grenadier is "common". We do not believe it has reoccurred since 1976. We



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Figure 5.2.4 Relative Thermal Resistance over depth for Greenadier pond: 1966, 1976 and 1983.

Table 5.2.3.: Maximum and Peak Wind Speeds (kph) and Direction

YEAR	MONTH			
	May	June	July	August
1966				
max	51.5(W)	35.3(SW)	40.2(W)	38.6(N)
peak	69.2(WNW)	59.5(SW)	48.0(WNW)	78.8(S)
1976				
max		39(E)	37(NW)	37(SW/NNW)
peak		56(NW)	59(WNW)	50(WNW)
1983				
max	59(SW)	35(NW)	31(SW)	43(NNW)
peak	109(WSW)	57(NW)	56(SW)	82(NW)

Source: Environment Service of Canada/Monthly Weather Summary

know it has not since 1978. First, we find no evidence that particularly "strong winds from the north or south" occurred prior to the 1976 turnover. Secondly, limnology classes at the University of Toronto have sampled Grenadier every fall since 1978. Early September profiles of temperature and oxygen have always shown remnants of stratification, rather than the isothermal, oxygenated profiles characteristic of 1976. Although an arguably minor point, the commonplace versus rare nature of mid-summer system turnover does have implications for maintenance of some aquatic species ("fish kills", overall system oxygen reduction, injection of sulfides, etc.) and may play a role in selection of appropriate species management or appropriate protocols for programs of nutrient modification. We believe the usual condition of Grenadier is moderately well stratified, and dimictic with anoxic lower waters. If turnovers were "common" in the past, the data from the last 8 years suggest that it is polymixis that is now rare.

5.2.3. Catfish 1983

The thermal profiles for Catfish pond are presented in Figure 5.2.5. Although thermal stratification is somewhat irrelevant given the meromictic nature of the pond, thermal development over the summer does not appear that different from profile development in Grenadier. Epilimnetic (mixolimnetic) waters warmed up over the sampling period, while the hypolimnetic waters remained relatively constant. Mixolimnetic cooling takes place at the same time (cycles

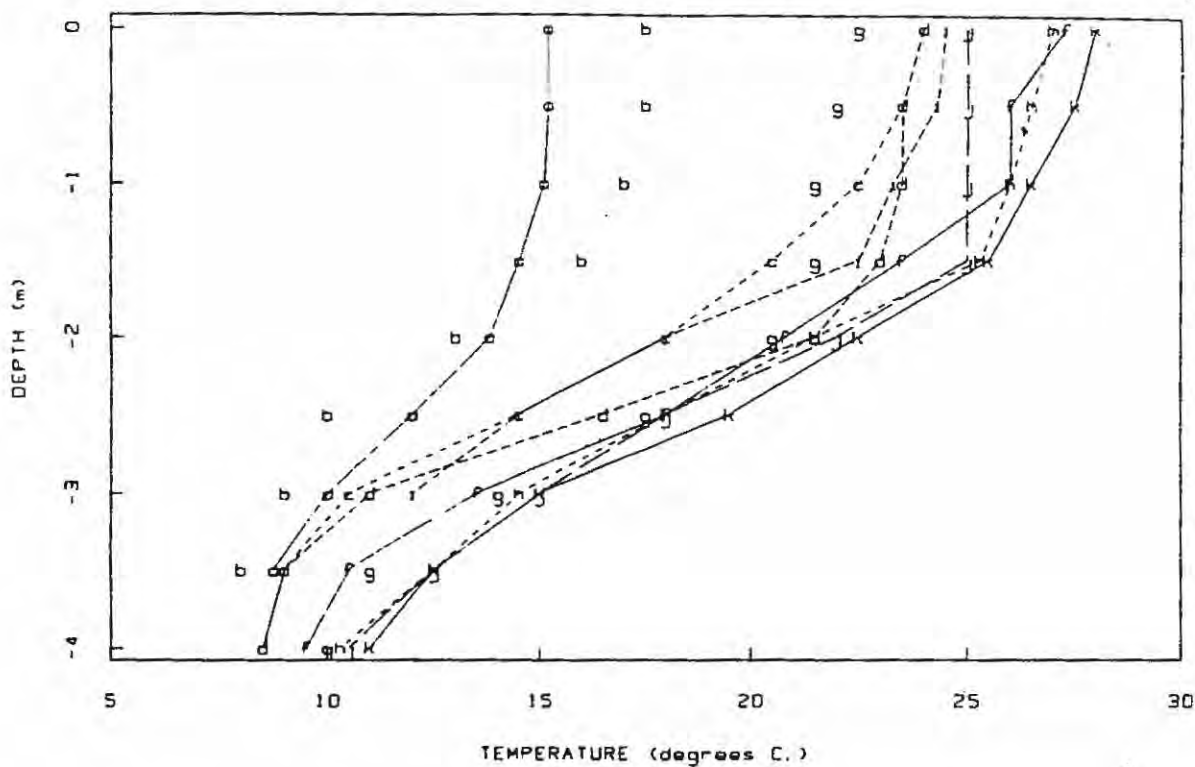


Figure 5.2.5. Depth-Temperature plot for Catfish pond, summer 1983.
Letters a-k represent sequential weekly samples.

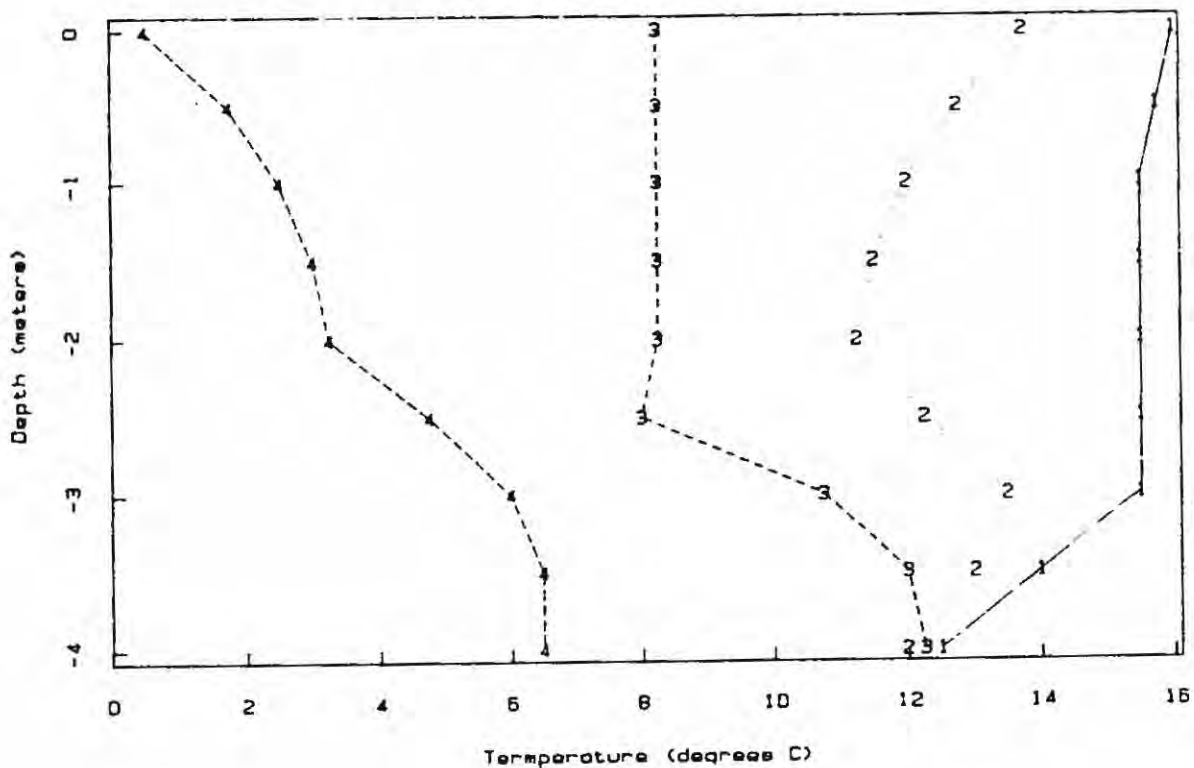


Figure 5.2.6. Depth-Temperature plot for Catfish pond, 1978 - 79.
1 = Sept. 19, 2 = Oct. 10, 3 = Nov. 7, 4 = Feb. 6

7 and 9) as in Grenadier (as well as in cycle 5). There is no entrainment of the upper warmer water into the cooler lower water as happened in Grenadier; due either to reduced winds acting on the fetch (Section 4.2) with subsequently reduced turbulent mixing or the effect of the density barrier at the chemocline.

Surface waters were approximately the same temperature in both ponds with identical maximum surface water temperatures (28 ° C) although the maximum temperature in Catfish occurred during the last cycle while maximum surface temperature in Grenadier were reached during cycle 8. The monimolimnetic ("hypolimnetic") waters showed only a slight increase in temperature, ranging from 6 ° C. to 11 ° C near the sediment-water interface. Consequently, comparisons of mean, volume weighted temperatures between the ponds shows Grenadier as slightly warmer than Catfish (21.9 ° C. and 19.09 ° C. respectively).

The meromictic condition of the pond leads to quite interesting annual behavior of thermal profiles. Figure 5.2.6. shows selected temperature profiles from Catfish taken during 1978-79. Since temperature is not the major factor controlling water density in Catfish, the system does not "turn-over" at the point when it becomes isothermal (Oct. 10 to Nov. 7). This leads to the somewhat unusual thermal pattern (Nov. 7 and Feb. 6) in which the lower waters of the pond are warmer than the surface waters. While unusual in the context of the "normal" thermal behavior of lakes, such *dichothermic* temperature patterns are actually characteristic of ectogenic meromictic lakes (Wetzel, 1983). As winter progresses the monimolimnion slowly cools but temperatures never do fall as low as those of the surface waters.

5.3. Dissolved Oxygen

5.3.1. Grenadier 1983

The oxygen concentrations observed in Grenadier are typical of a eutrophic system (Wetzel, 1983). The profile is clinograde with the surface waters generally at or above saturation and the lower waters progressing from low, sub-saturation levels to anoxia, Figure 5.3.1. and Appendix 1. Sediment oxygen demand is quite high and the lowest meter of water is virtually anoxic from cycle 2 on, the lower 3 meters are anoxic by cycle 6. Wind associated mixing (see previous Section 5.2.1.) between cycles 8 and 9 entrains some oxygen to a depth of 4.5m, but the general pattern of anoxia below 3 meters is re-established by cycle 10. (See Section 6.1., Primary Production, for a discussion of hypolimnetic oxygen demand in Grenadier.)

Concentrations of oxygen at the Grenadier B site fluctuated throughout the sampling period, but never reached anoxic conditions. Raw data for Station B are in Appendix 1.

5.3.2. 1983-1976 Comparisons in Dissolved Oxygen

The volume weighted mean of dissolved oxygen for 1983 was 7.2 mg.L^{-1} compared to the 1976 volume-weighted mean of 6.7 mg.L^{-1} calculated from the Wainio *et al.*, 1976, data (Appendix 2). Water quality, defined as transparency, has improved in Grenadier since 1976 (Section 5.7.4). There also appears to be some improvement in oxygen concentration. The Wainio *et al.* data are only for selected depths, generally 2 and 5 m. However, their upper water values range from 4.6 to 12.2 mg.L^{-1} . The 1983 upper water data range from 8 to 14 mg.L^{-1} . The 1976 bottom waters are anoxic at 5 meters from cycle 2 (9 June) onward although there is oxygen at 4 meters on that date. After water column turnover on 11 July, 1976, the pond appears to have circulated more or less freely and there is oxygen present in the lower waters (at least at 5 meters) through the remainder of the 1976 sampling year. These post turn-over oxygen values are never at saturation which might be expected given the

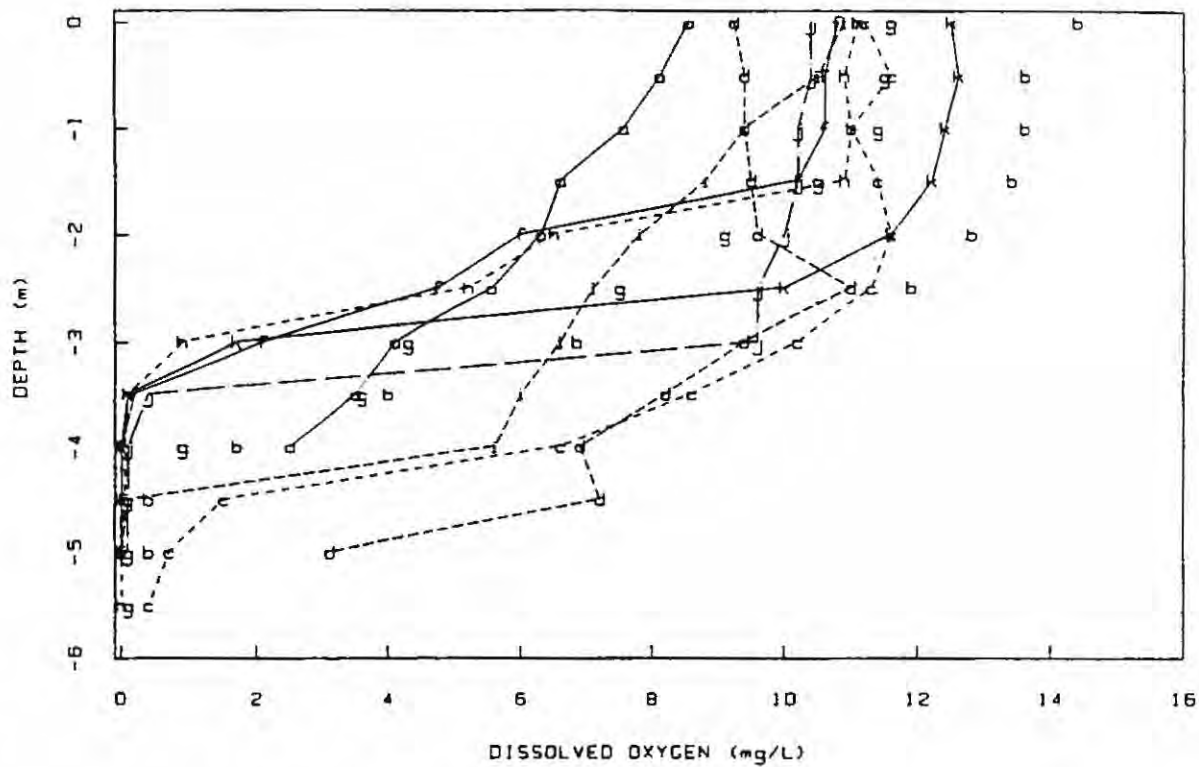


Figure 5.3.1. Depth-Dissolved oxygen plot for Grenadier pond, summer 1983. Letters a-k represent sequential weekly samples.

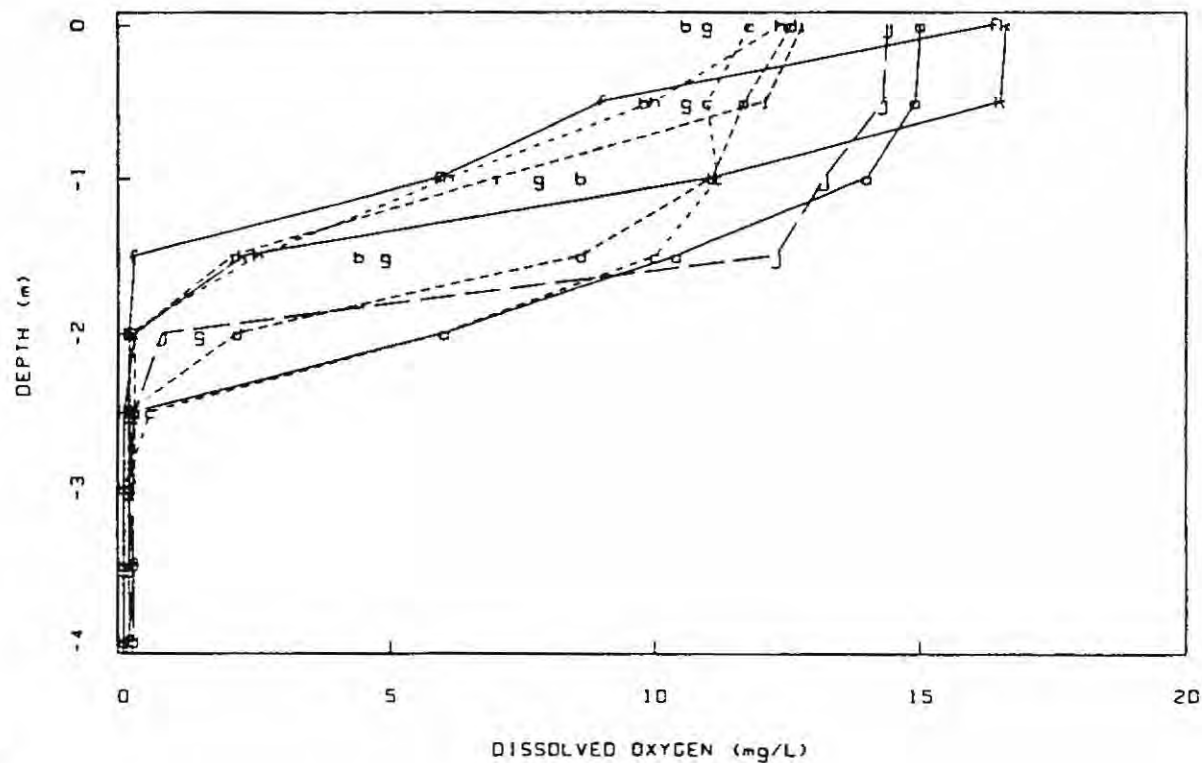


Figure 5.3.2. Depth-Dissolved oxygen plot for Catfish pond, summer 1983. Letters a-k represent sequential weekly samples.

injection of reduced materials from the hypolimnion and the high oxygen demand of the sediments which is now being distributed throughout the water column. The 1983 data show that the bottom waters were anoxic by cycle 6 (*i.e.* the 4th of July versus the 9th of June or almost a month later in 1983 as compared to 1976).

5.3.3. Catfish 1983

The dissolved oxygen curves for Catfish are presented in Figure 5.3.2. The curves are clino-grade as in Grenadier, although the surface values are slightly higher and the waters of the monimolimnion are always anoxic. Surface oxygen conditions are often supersaturated as they are in Grenadier. The slightly higher nature of the values presumably reflects the generally higher levels of productivity in Catfish (Section 6.1).

Cycle 1 shows the deepest penetration of oxygen. Anoxia begins as the summer progresses, the zone of anoxia and/or low oxygen conditions generally moves upwards. This upward migration presumably reflects a combination of oxygen used for respiratory activity of organisms (light is almost completely attenuated below 1 meter), decomposition of detrital material accumulating on the chemocline and perhaps oxidation of reduced compounds migrating out of the monimolimnion. There is some evidence for a minor entrainment of oxygen concomitant with wind-induced mixing (cycle 7) as well as with no apparent wind bases (cycle 6) but the progressive pattern of upward migration of low oxygen reasserts itself. The effect of the large volume of anaerobic water is evident in a comparison of volume weighted mean oxygen values between the ponds. The value for Grenadier is 7.7 mg.L^{-1} while the volume weighted mean oxygen value for Catfish is 6.6. A non-volume weighted mean for the mixolimnion, 8.9, reflects the generally higher oxygen values associated with the increased productivity of Catfish.

5.4. pH

5.4.1. Grenadier 1983 and 1976

The pH of Grenadier is relatively high (*i.e.* > 7.5), as might be expected for a eutrophic system with carbonate geochemistry. pH generally decreases with respect to depth (Figure 5.4.1.) and increases with increases in oxygen concentration. Both patterns suggest that photosynthesis and respiration are the primary influences for pH fluctuations in this system.

Volume weighted mean pH was 7.9 in 1983 and 7.6 in 1976. Given the above, we do not feel the differences represent anything particularly substantive and reflect the lower oxygen concentrations (*i.e.* higher respiratory activity) associated with 1976 (See preceding Section 5.3.2). Data for 1983 can be found in Appendix 1, for 1976 in Appendix 2.

5.4.2. Catfish 1983

Profiles of pH for Catfish can be found in Figure 5.4.2. Comparison of the profiles in Catfish with those from Grenadier indicates that the mixolimnion pH's in Catfish are slightly higher than the epilimnetic values of Grenadier, while the monimolimnion values are slightly lower than those from the lower waters of Grenadier. Comparisons of the volume weighted mean pH for Grenadier (7.9) with the mean for the mixolimnion (8.1) and the volume weighted mean for the entire water column of Catfish (7.6) reflect these differences. As in Grenadier, photosynthesis and respiration are expected to be the primary influences on pH, the higher values in the mixolimnion relative to Grenadier reflecting the higher rates of primary productivity in Catfish, the lower values in the monimolimnion relative to Grenadier reflecting the intense levels of decompositional/respiratory activity ongoing in Catfish.

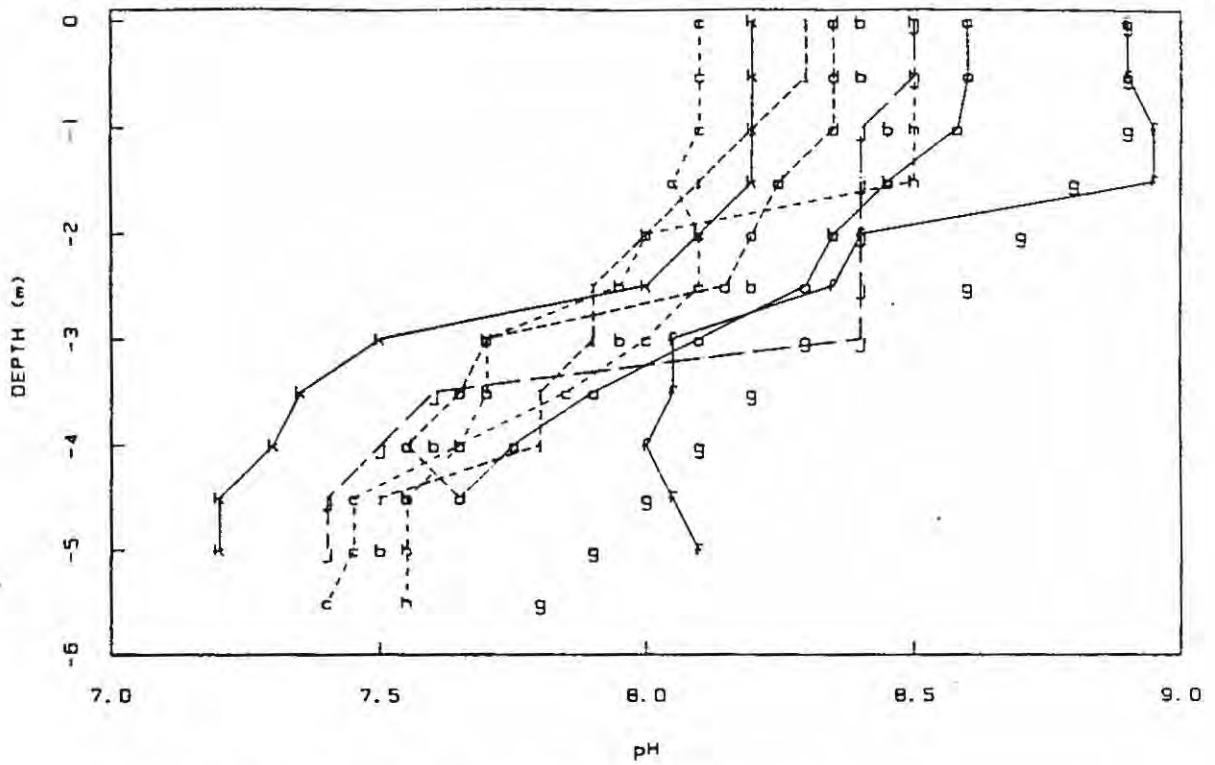


Figure 5.4.1. Depth-pH plot for Grenadier pond, summer 1983.
Letters a-k represent sequential weekly samples.

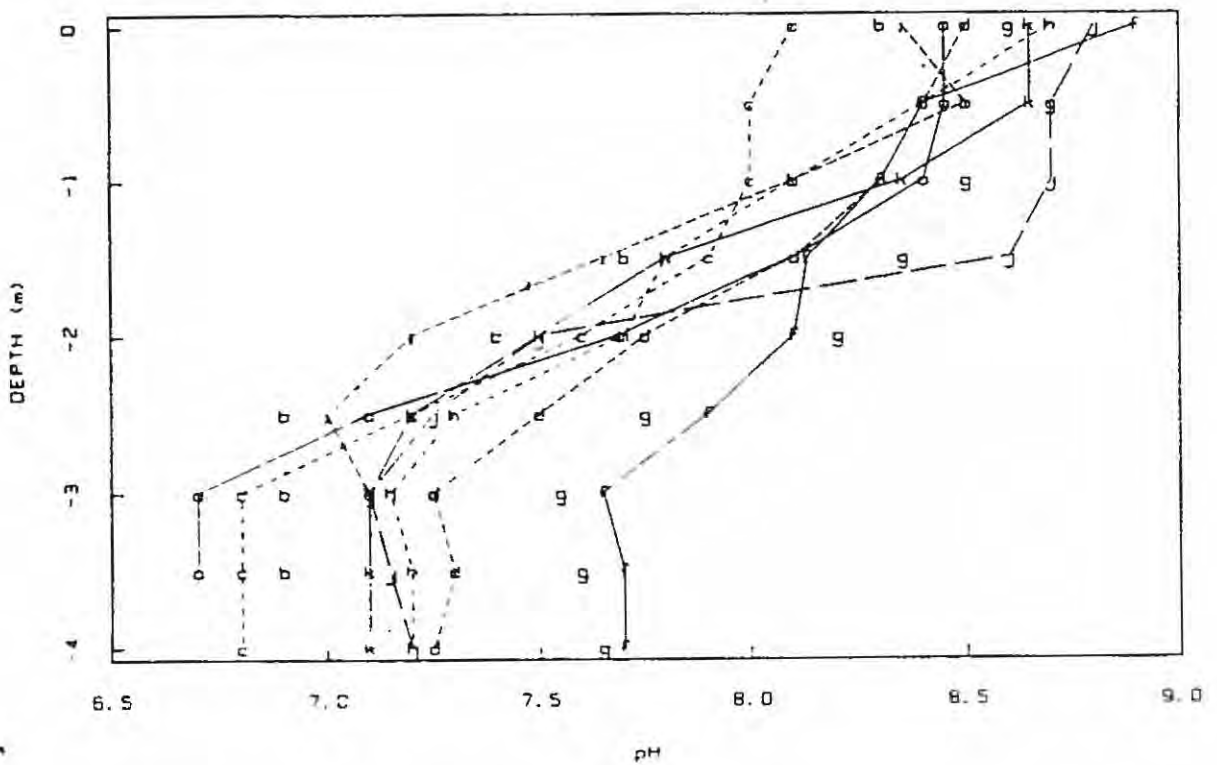


Figure 5.4.2. Depth-pH plot for Catfish pond, summer 1983.
Letters a-k represent sequential weekly samples.

5.5. Conductivity

5.5.1. Grenadier 1983

In general surface values of conductivity are relatively uniform increasing slightly near the bottom (Figure 5.5.1.). Conductivity tends to increase near the sediment-water interface particularly in anaerobic systems as ions are released from the sediments. Alternative/additional sources of ions may be sedimented materials from the upper waters and exchange of ions from clays, organics, etc. There are no conductivity values from 1976 (Wainio, *et al.*) for comparison to this study.

In general, the pattern of conductivity is that expected for a hard water, high carbonate, eutrophic system. However, the magnitude of the values is substantially higher than those found in either the Lower Great Lakes or other inland carbonate-bicarbonate systems in Ontario. Section 5.8, Chemical Parameters, discusses the chemistry of Grenadier Pond with respect to these other aquatic systems. However, it seems fairly clear that most of the elevation in conductivity is accounted for by elevated chloride and chloride counter-ion.

Table 5.5.1.: Equivalent Percentages of Conductivity in a Series of Ontario Lakes

	Lake Ontario	Lake Eric	K-lakes ¹	O-lakes ²	Grenadier	Catfish	Catfish Monimolimnion
Ca	34.6	31.7	46.9	37.3	13.2	9.4	2.5
Mg	7.6	9.9	7.8	10.3	5.7	6.8	1.0
Na	8.1	7.7	1.6	3.4	24.8	29.6	25.5
K	1.0	0.7	0.9	0.9	0.4	1.9	1.2
Cl	17.7	16.8	1.5	5.3	29.3 ³	30.8 ⁴	59.6 ³
HCO ₃	25.5	26.0	42.8	39.1	7.1 ⁴	4.3 ⁴	44.0 ⁴
SO ₄	17.0	12.2	10.9	7.7	7.0	4.0	0.3 ³
cond	320	302	155	230	1555	1700	16333

1 averages from 5 Kawartha area lakes (Zimmerman, *et al.*, 1983)

2 averages from 5 Orillia area lakes (Zimmerman, *et al.*, 1983)

3 taken from Neutron Activation Analyses (see Appendix 3)

4*(see Appendix 3)

5 assumed to be 100% S²⁻

Table 5.5.1. presents equivalent conductivities attributed to major ions in Grenadier, Catfish and several other lake ecosystems. In Lake Ontario, Erie, selected Kawartha and Orillia area lakes systems, sodium and chloride account for an average of 5.2 and 10.3% of conductivity respectively. In Grenadier, sodium accounts for 29.8 and chloride 29.3% of conductivity. Similarly sodium and chloride account for more of the explained variance (99.8%) in conductivity than any other element in the matrix (see Table 5.8.1., Section 5.8.1.).

5.5.2. Catfish 1983

Conductivity profiles for Catfish are also presented in Figure 5.5.1. They reflect the general meromixis previously discussed (see section 5.1.3.). Comparison of volume weighted mean conductivities between Grenadier and Catfish (1555 $\mu\text{mho}\cdot\text{cm}$ in Grenadier and 4728 $\mu\text{mho}\cdot\text{cm}$ in Catfish) are misleading due to the tremendous contribution to conductivity from the monimolimnion. However the mean mixolimnetic conductivity value from Catfish is also higher than that of Grenadier (1851 $\mu\text{mho}\cdot\text{cm}$) suggesting that chemical loads in general are higher in Catfish (see Section 4.1. which details watershed inputs), mixolimnetic flushing is reduced over Grenadier or that there is some diffusion and/or entrainment of materials from the monimolimnion into the mixolimnion. The fact that Na and Cl are enriched relative to the other elements in the mixolimnion, rather than in the same proportions as in Grenadier (see Table 5.5.1.) tends to support the latter hypothesis.

5.6. ORP or pE

5.6.1. Grenadier 1983

As expected, the oxidation-reduction potential (ORP) or pE, closely follows the dissolved oxygen concentration in Grenadier, remaining reasonably high and positive in the surface waters where oxygen is high, Figure 5.6.1. and Appendix 1. In the lower waters where anoxia

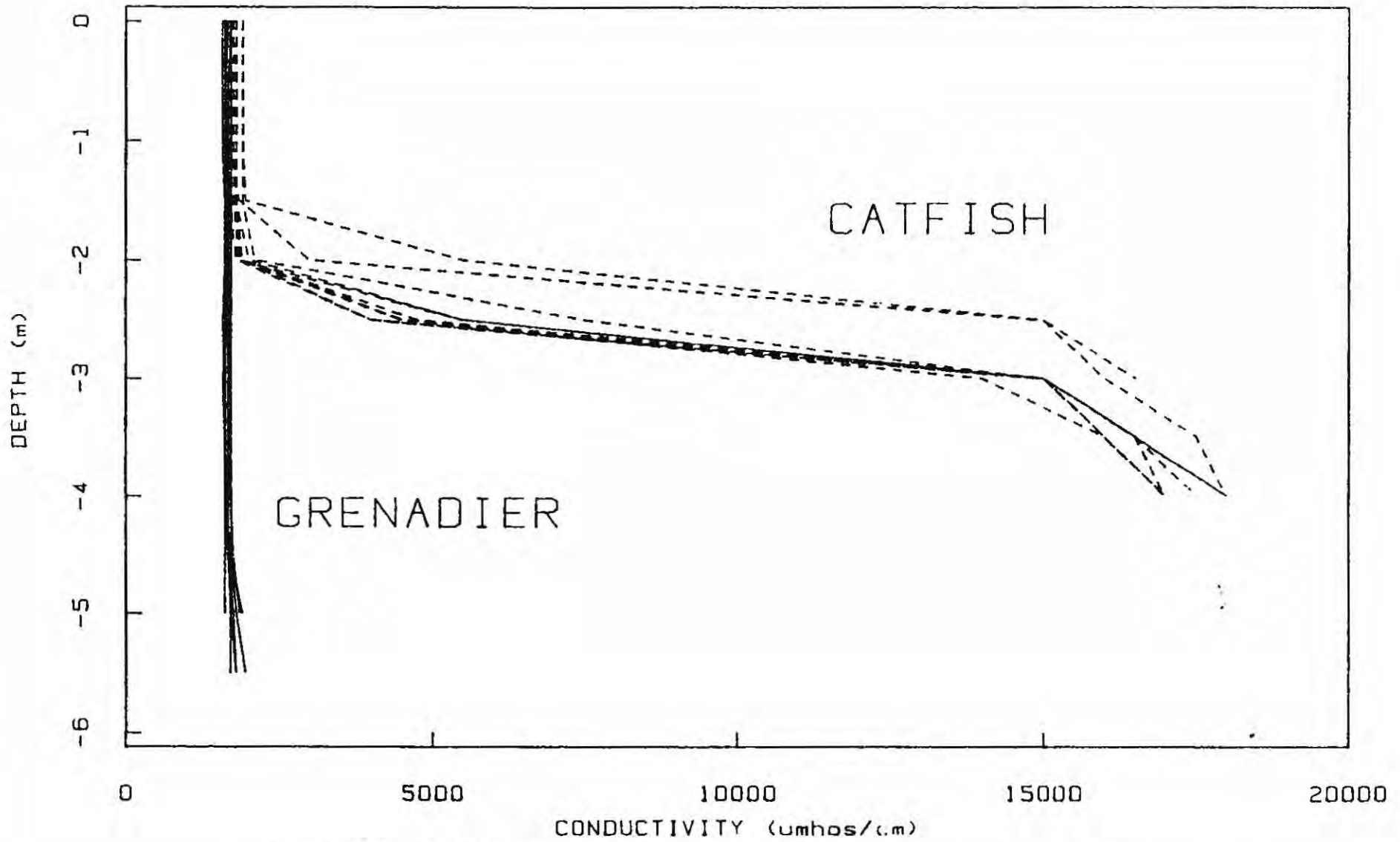


Figure 5.5.1 Depth-Conductivity plots for Grenadier and Catfish ponds in the summer of 1983.

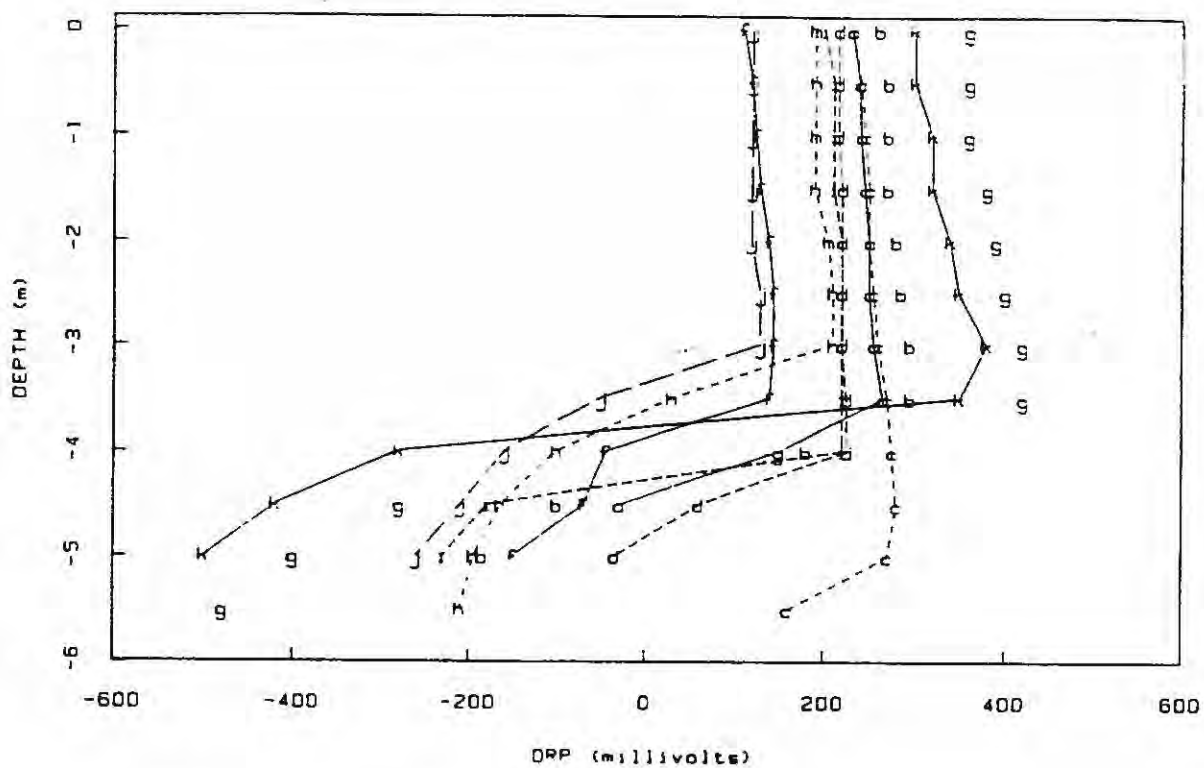


Figure 5.6.1. Depth-ORP plot for Grenadier pond, summer 1983.
 Letters a-k represent sequential weekly samples.

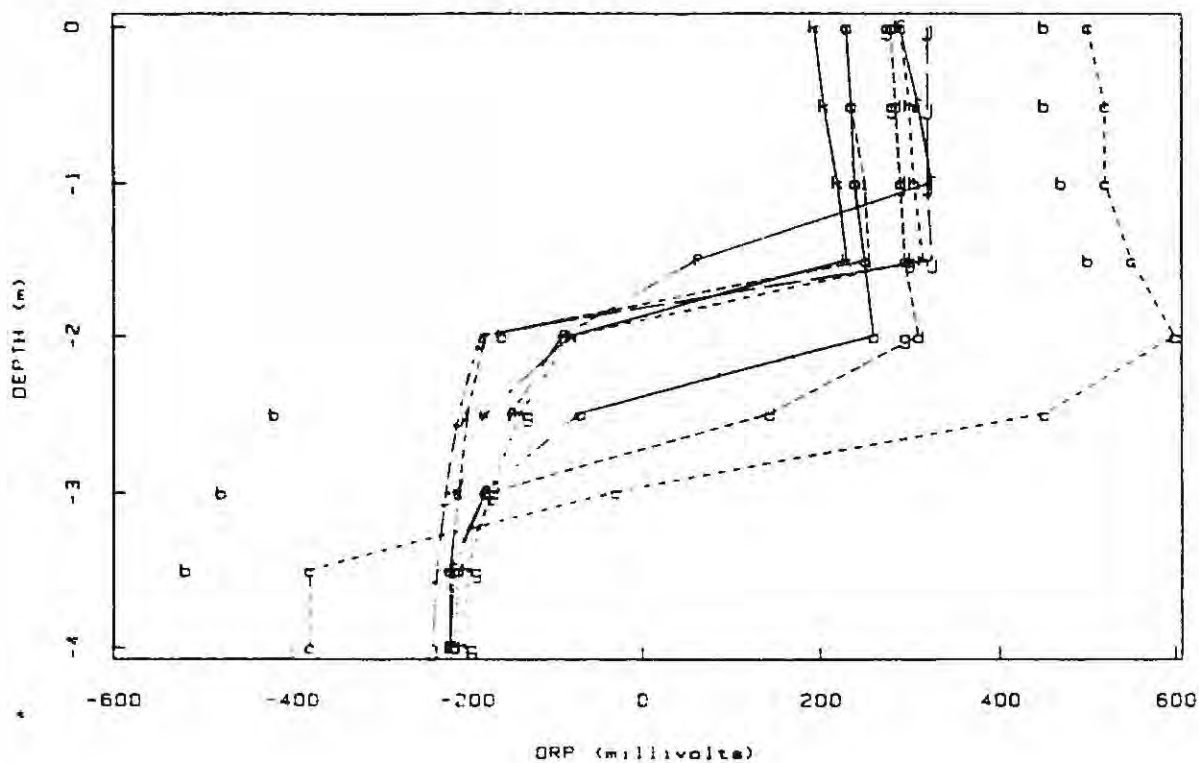


Figure 5.6.2. Depth-ORP plot for Catfish pond, summer 1983.
 Letters a-k represent sequential weekly samples.

occurs, the ORP is correspondingly negative indicating reducing conditions. Upper water values ranged from 110 to 360 mv (pE = 5.3 to 9.5), while the values for the anoxic lower waters were -30 to -480 (pE = 2.9 to -4.7).

5.6.2. Catfish 1983

Oxidation reduction potential profiles for Catfish are presented in Figure 5.6.2. As in Grenadier, the ORP values for the pond closely follow the oxygen values; high, positive and oxidizing in the upper two metres where oxygen is present; low, negative and reducing in the lower waters where anoxic conditions prevail. Values in the mixolimnion ranged from +200 mv (pE = +6.8) to +500 mv (pE = +11.8) while values below the chemocline ranged from -70 to -380 mv (pE = +2.2 to -3.1). Mean volume weighted ORP values for the two ponds are similar, 168.7 mv (pE = 6.2) in Grenadier and 164.0 mv (pE = 6.1). In both ponds, reducing pE's (and hence volume weighted means) are probably poised between -2 and -4 by the sulfate-sulfide redox couple.

5.7. Transparency and Light Attenuation

5.7.1. PAR in Grenadier

The quantum sensor measures extant electromagnetic radiation of approximately 400-700 nm with a response peak somewhere near 550 nm (photosynthetically active radiation or PAR). The gradual attenuation of light with respect to depth is logarithmic. Hence the extinction coefficient is the slope of the \log_e of irradiance against depth. In the interest of more immediate comprehensibility, the extinction coefficient or $-n$ is often expressed as the percentage of light transmitted or absorbed per meter ($100 \exp -n$ and $100 (1-\exp -n)$ respectively).

Light attenuation in Grenadier is plotted in Figure 5.7.1. At station A in Grenadier slopes are reasonably parallel with extinction coefficients that range from 0.49 (38.7% light absorbance per metre) to 1.6 (79.8% absorbance per metre). Later cycles (6-11) show abrupt changes in

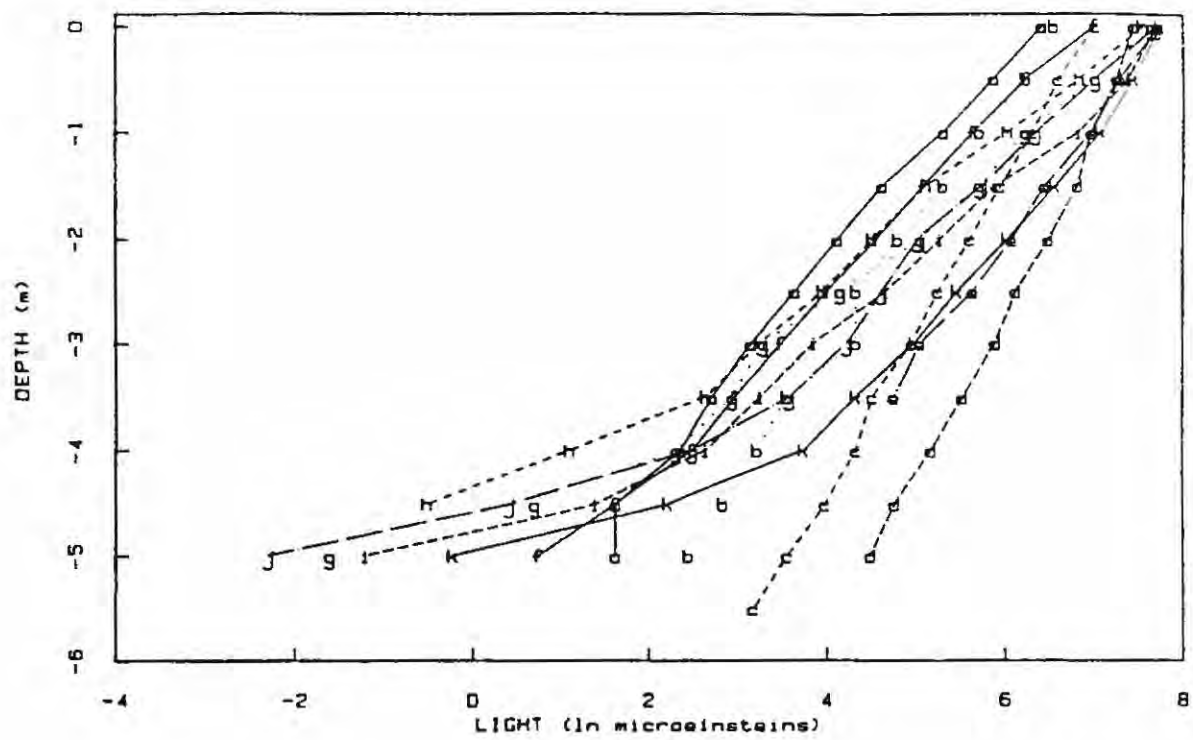


Figure 5.7.1. Depth-Light plot for Grenadier pond, summer 1983.
 Letters a-k represent sequential weekly samples.

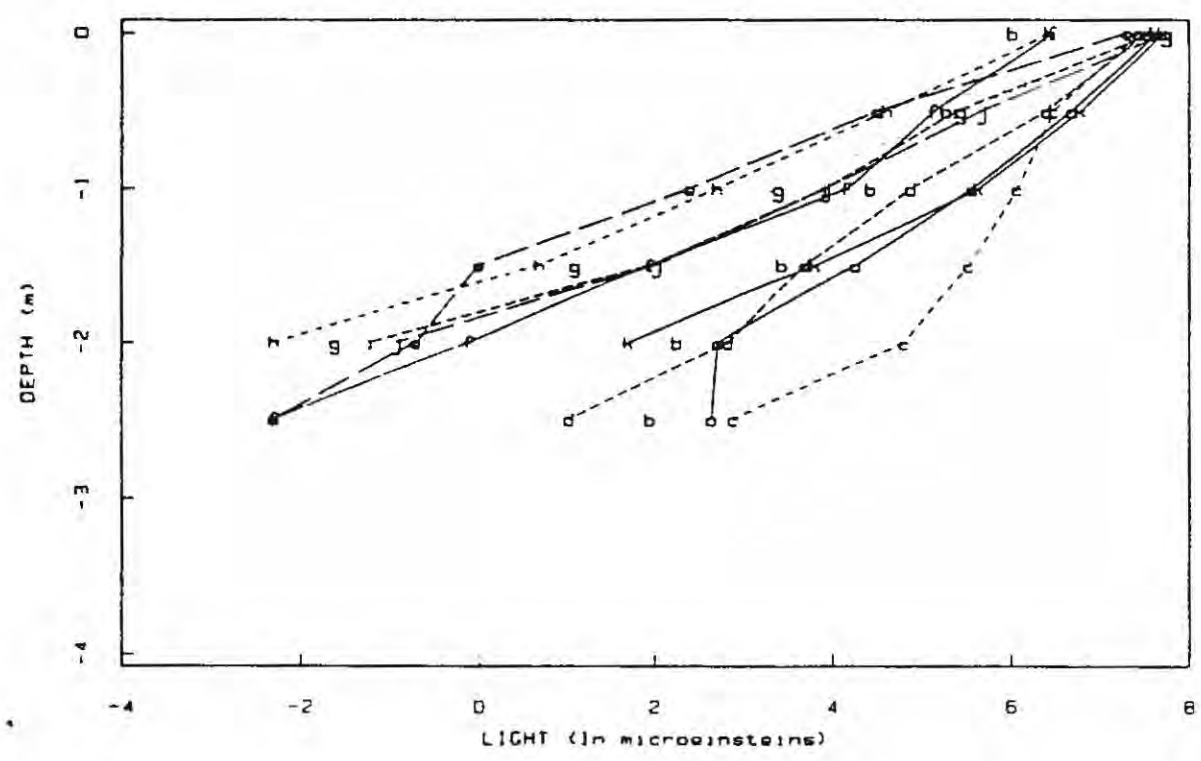


Figure 5.7.2. Depth-Light plot for Catfish pond, summer 1983.
 Letters a-k represent sequential weekly samples.

slope at approximately 4 metres. Light values after the slope change were not included in the calculation of the extinction coefficient. These increases in the rate of light attenuation reflect changes in absorption characteristics of the water and are probably due to suspended particles.

At station B, light penetrates to the bottom for all cycles.

5.7.2. PAR in Catfish

Light attenuation profiles for Catfish are presented in Figure 5.7.2. Light attenuates more rapidly in Catfish than in Grenadier and slopes are more consistently parallel with extinction coefficients that range from 1.3 (72.7% absorption per metre) to 2.5 (99.0% absorbance per metre). The abrupt changes in slope that occurred in Grenadier and might be anticipated at the chemocline in Catfish do not materialize since light is virtually completely attenuated by 2 meters.

5.7.3. Secchi in Grenadier and Catfish

As opposed to the quantum sensor which measures the actual quantity of transmitted light, the secchi estimates the relative ability of light to penetrate water. Generally the secchi disk depth approximates the depth to which 10% of incident light penetrates. Since light attenuates logarithmically, twice the secchi depth approximates the 1% incident light level and represents the boundary beyond which algae are theoretically light limited. Consequently, the secchi disk depth is often used as an indicator of the depths at which to incubate light-dark bottles for estimates of primary production (see Section 6.1., Primary Production). In most lakes however, the agreement between the secchi disk depth and actual attenuation of PAR ranges from about 5 to 15% of incident radiation (Wetzel, 1983), the actual percentage usually being some function of suspensoid concentration or dissolved color in the system.

Extinction coefficients and percent transmittance per metre for the two ponds are presented in Table 5.7.1. The secchi depth for Grenadier A started out at about 2m for the first 2 cycles, progressively deepened to 4m by cycle 4 and then averaged 1.2m (range 0.8-1.3m) for the remainder of the summer (Table 5.7.1.). Mean secchi was 2.0m. At Grenadier B, the secchi depths ranged from 0.8m to the bottom (1.5m). These transparency patterns correspond reasonably well to the changes in phytoplankton biomass as represented by chlorophyll. Shallow secchi and high chlorophyll occurring at the first sampling period, deeper secchis (clearer water) and lower chlorophylls through cycle 5, followed by higher chlorophyll values and corresponding shallower secchis for the remainder of the summer period.

Table 5.7.1.: Extinction Coefficients (-n),
Percentage Absorption per Metre (% absorption)
Depth of 10% PAR and Secchi Disk Depth (SDD)

cycle	Grenadier				Catfish			
	-n	% absorption	10% PAR	SDD	-n	% absorption	10% PAR	SDD
1	1.0	65.0	2.2	1.8	2.5	91.8	0.9	0.8
2	.89	58.9	2.8	3.0	1.8	83.5	1.2	1.3
3	.67	48.8	3.3	3.5	1.3	72.7	--	--
4	.49	38.7	4.2	4.0	2.6	92.6	1.8	0.7
5	.83	56.4	2.7	2.2	3.8	97.8	1.0	0.5
6	1.1	66.7	2.0	1.5	3.3	96.3	0.6	0.5
7	1.3	72.7	1.7	1.5	4.6	99.0	0.7	0.5
8	1.6	79.8	1.6	0.8	4.6	99.0	0.5	0.5
9	1.4	75.3	1.7	1.0	4.6	99.0	0.5	0.5
10	1.3	27.3	2.0	1.0	3.8	2.2	0.5	0.5
11	.95	61.3	2.3	1.2	2.8	93.9	0.8	0.5

Secchis in Catfish started out at 0.8m, deepened to 1.8m and then remained at 0.5m for the remainder of the summer. Mean secchi was 0.6m. Transparency patterns in Catfish are less sensitive to changes in chlorophyll than was the case in Grenadier. The first increase in secchi from 0.8 to 1.3 does correspond to decreasing chlorophyll, but the secchi continues to deepen to 1.8m while chlorophyll remains virtually the same. Progressive decreases in secchi to 0.5 through cycles 4 and 5 correspond to increases in chlorophyll in those cycles but the secchi then remains at 0.5 while total chlorophyll values vary between 6.1 and 77.1 mg. m⁻³.

The relationship between the secchi disk depth and the actual depth at which 10% of PAR occurs are plotted in Figure 5.7.3. The primary line (-----) corresponds to a secchi that estimates the actual depth of 10% PAR penetration. It is bounded by lines (.....) that represent the 5 and 15% depths. The relationship between secchi and 10% PAR in Catfish is good, all cycle values for Catfish fit within the 5-15% envelope of Figure 5.7.3. The slope indicates that the secchi approximates the depth to which 13% of PAR penetrates.

While the relationship between secchi and 10% PAR is reasonably good in Grenadier the slope (0.67) suggests that secchi disk depth greatly underestimates the depth to which 10% of PAR penetrates in Grenadier. Table 5.7.1. indicates that the actual percentage of PAR represented by secchi varies from an 8% overestimate to a 105% underestimate.

On a cycle-by-cycle basis, Figure 5.7.3. suggests that cycles 1-7 will fit the 5-15% envelope leaving only cycles 8 - 11 as outliers. It is these cycles that Table 5.7.2. indicates are also the most discordant, i.e. the Secchi indicates that the water is at its murkiest while the actual depth of 10% PAR penetration is around 2 metres (1.6-2.3m). These are also the cycles during which nanoplankton numbers are the highest in Grenadier (see Figure 6.3.1., Section 6.3.) and suggesting that there is some critical value of suspensoids above which the nature of the secchi disk depth-10% PAR relationship changes. However, nanoplankton biomass in Catfish is significantly higher than in Grenadier and ranges across values an order of magnitude apart with no apparent shift in secchi-PAR slope.

In and of itself the failure of secchi to precisely predict a given amount of incident radiation is relatively immaterial. In the absence of an *ex situ* incubator, the secchi is used as a guide for *in situ* incubation of light-dark bottles. A secchi depth greater or less than 10% incident light will result in over or underestimates of the extent of the euphotic zone, misrepresentation of the nature of the photosynthetic profile and subsequent error in calculations of areal primary productivity. These can be reasonably well corrected by subsequent referral to the PAR profile and merely should underscore the need for photon flux data for estimates of productivity. Despite the existence of a theoretical relationship between secchi and 10% PAR, it is

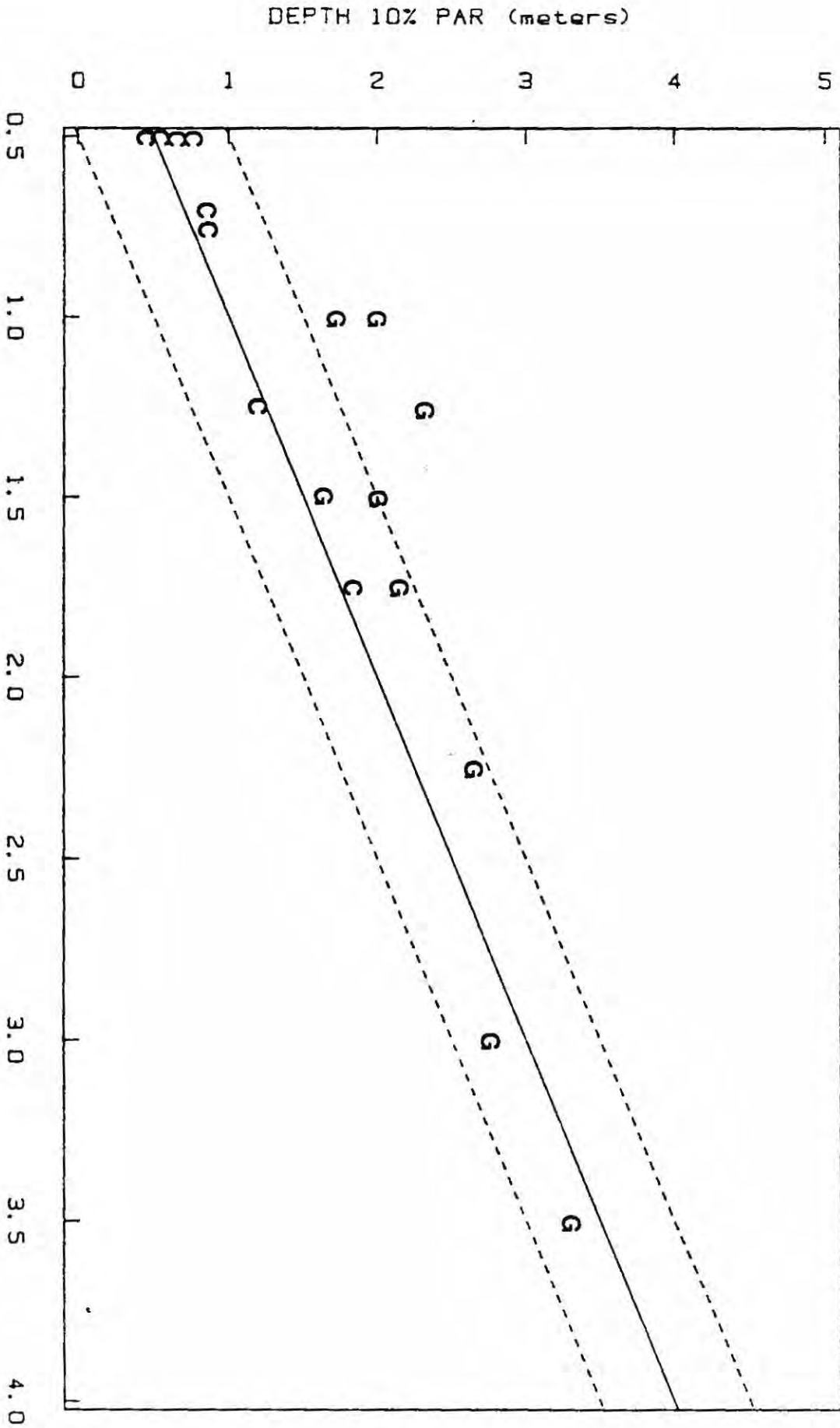


Figure 5.7.3. Depth of 10% Photosynthetically Available Radiation (PAR)

interesting that primary productivity as determined by net oxygen evolution does not occur down to the depth of twice the secchi in either pond and hence does not occur at PAR levels above 10%. While there is evidence of some oxygen evolution in the light bottle at the 2X secchi depth, photorespiratory or photochemical BOD always reduces the light bottle oxygen concentration to less than that of the initial (Section 6.1.).

5.7.4. Grenadier 1983 and 1976

Wainio *et al.* (1976) report Grenadier secchi depths varying from 0.7 to "less than 1 m". There are no specific dates given for the secchi data collection. It is possible that the shallow secchis were all taken after the July turnover. If however the data span the 1976 sampling season, our secchi values which range from 0.8m to 4.0m indicate that transparency in Grenadier is considerably improved over 1976. Actual improvements in water quality are supported by comparisons of oxygen data (Section 5.3.2), pH data (section 5.4.1) and changes in zooplankton community structure (Section 4.6.2.).

5.8. Chemical Parameters

Nutrients were monitored at 1 and 2 week intervals based on the conservative non-conservative nature of each element. Comparisons of means and standard deviations for a data set N = 11 (samples collected every week) and a data set N = 7 (samples collected every week) show no significant differences. Alternative week sampling should be adequate for a program of routine monitoring.

5.8.1. Mean Nutrient Chemistry: Grenadier and Catfish 1983

Mean primary water chemistry data are presented in Table 5.8.1. Cycle by cycle data can be found in Appendix 8. Stations A and B in Grenadier are quite similar. Iron appears somewhat elevated at Station B but none of the differences between the 2 stations are significant ($p < .01$).

Table 5.8.1.: Mean Primary Water Chemistry
For Grenadier and Catfish ponds.

Variable (g.m ⁻³)	GA	G-B	C	H-C	%HC/C
Mg	22.7	22.8	30.4	35.8	117.8
Na	176.5	176.4	235.7	1960.0	832.7
K	3.68	3.60	17.70	24.9	140.7
Mn	0.114	0.075	0.126	2.68	21.27
Fe	0.099	0.285	0.338	1.40	414.2
SO ₄	71.60	73.60	51.14	30.49	--
SiO ₃	3.07	2.73	2.21	6.8	307.3
TP	0.086	0.087	0.118	4.58	3881.4
SRP	0.038	0.034	0.07	3.7	--
NH ₄	0.27	0.377	0.32	--	--
NO ₃	<.06	<.017	.078	--	--
NO ₂	0.12	0.01	0.124	0.016	--
TKN	0.82	0.86	1.36	--	--
DOC	3.08	3.08	5.0	7.5	--

GA - Grenadier site A, GB - Grenadier site B, C - Catfish,
H-C - Catfish hypolimnion, %HC/C - % of Catfish values di-
vided by Catfish hypolimnion

Most elements appear lower in Grenadier than Catfish. However only the differences in Mg, Na, K, Fe, and DOC are significant ($p < .01$). SO₄ and SiO₃ are the only two elements appearing higher in Grenadier but only the differences in SO₄ are significant ($p < .01$). The only difference that appears greatly out of line is in the potassium data. Mean K in Catfish is 17.7 mg.L compared to 3.6 mg.L in Grenadier. We have no explanation for the unusually high K levels in Catfish. While K itself has no toxic properties the high levels suggest further chemical sampling for a possibly toxic counter ion be undertaken (cyanide). All elements with the exception of NO₂ are elevated in the monimolimnion of Catfish.

Comparisons of system chemistry in Catfish and Grenadier, relative to other hardwater lake systems, show that all major metals and ligands are elevated (Table 5.8.2.), although the elevation in Na and Cl stand out; Na comprises 56.2 and 60.1% of cations in Grenadier and Catfish compared to 2.8 - 16.4% in less impacted systems.

Elevated major ion composition probably only reflects the generally higher loadings imposed on urban systems. If it exerts any effects on the biology of the system other than the

Table 5.8.2.: Metal and Ligand Equivalence Comparisons and Equivalent % for Grenadier, Catfish, and Other Selected Lakes.

	Lake												
	Ontario		Eric		K Lakes		O Lakes		Grenadier		Catfish		Catfish monimo-limnion
	(%)		(%)		(%)		(%)		(%)		(%)		
Ca	2.14	66	1.84	61.5	1.40	80.9	1.65	70.2	3.94	29.1	3.9	22.8	--
Mg	0.53	16.4	0.64	21.4	0.26	15.0	0.51	21.7	1.90	14.1	2.50	14.6	2.9
Na	0.53	16.4	0.48	16.1	0.05	2.8	0.16	6.8	7.60	56.2	10.30	60.1	85.30
K	0.04	1.2	0.03	1.0	0.02	1.2	0.03	1.2	0.09	0.6	0.44	2.6	0.64
Cl	0.75	22.2	0.67	22.6	0.03	1.7	0.16	6.5	6.00	44.4	6.90	42.3	128.40
IC	1.88	55.6	1.80	60.6	1.52	85.4	2.06	83.7	6.00	44.4	8.40	51.5	154.00
SO ₄	0.75	22.2	0.50	16.8	0.23	12.9	0.24	9.8	1.50	11.1	1.00	6.1	0.6

meromixis inflicted on Catfish for morphological reasons (Section 4.2.) it might actually be beneficial in reduced respiratory costs associated with maintaining an optimal internal osmotic environment (H.H. Harvey, pers. com.). Eutrophication is the most obvious effect of elevated load and it is not directly associated with the major metals and ligands but with the potentially limiting micro nutrients, phosphorus and nitrogen.

5.8.2. Phosphorus and Nitrogen

Total phosphorus and total organic nitrogen levels place Grenadier and Catfish into the eutrophic or marginally hypereutrophic productivity class (Total Phosphorus > 100 mg m⁻³, Organic Nitrogen < 700-1200 > mg m⁻³). Total phosphorus averages 86.3 mg m⁻³ in Grenadier and 125.6 mg m⁻³ in Catfish. Organic nitrogen values are 833.0 mg m⁻³ in Grenadier and 1242.0 mg m⁻³ in Catfish. Total inorganic nitrogen values are somewhat lower than might be expected. Summer average values were 340.9 mg m⁻³ in Grenadier and 474.5 mg m⁻³ in Catfish. Values which place the ponds in the slightly less productive meso-eutrophic category (Wetzel 1983). Lower than expected inorganic nitrogen lends support to the hypothesis that the ponds are nitrogen rather than phosphorus limited.

Average total phosphorus values in Grenadier are substantially lower than those reported in Wainio *et al.* 1976 (83.6 versus 1200 mg m⁻³). Some of the differences in phosphorus concentration may reflect different methodologies, however, water clarity has improved substantially since 1976 (Section 5.7.4). A real reduction in phosphorus loading to the system may have occurred. However improvements in water quality as a function of decreasing phosphorus concentration does not square with the Wainio *et al.* contention that nitrogen is the limiting nutrient for algal growth in Grenadier.

The question of which element limits production in an aquatic system has implications for watershed management, phytoplankton dynamics and plankton nutritional quality over and above supporting/failing to support a primary causation hypothesis for water quality changes. Phosphorus is reasonably amenable to watershed control strategies and systems under phosphorus limitation respond reasonably quickly to reduced loadings. The large atmospheric pool of nitrogen confounds control of that nutrient and improvements in trophic status for systems under nitrogen limitation are difficult.

Wainio *et al.* (1976) base their suggestion for nitrogen limitation on the low inorganic N:P ratio (0.6). $\Sigma \text{NO}_3 + \text{NO}_2$ are substantially lower in 1983 than 1976 (95.9 mg.m⁻³ versus 500 mg.m⁻³). NH_4 levels are also reduced (212.2 versus 300 mg.m⁻³). Phosphorus levels are also lower so the 1983 total inorganic nitrogen:total phosphorus ratio remains low (3.6) and still indicates potential nitrogen limitation. However neither total inorganic nitrogen nor total phosphorus are significantly correlated to either chlorophyll or volumetrically determined phytoplankton biomass in Grenadier.

Soluble reactive phosphorus forms a relatively large percentage of total phosphorus in Grenadier (32.6%) relative to most lakes (reported ranges 5.9 - 13%, Wetzel 1983). High availability of this supposedly biologically available form of phosphorus is further evidence that phosphorus is not in particularly short supply. Section 6.5.3. suggests that biological interaction specifically zooplankton grazing on phytoplankton is the most important density regulating mechanism in Grenadier. If so, nutrients would be much less important in determining

biomass of phytoplankton: hence the nonsignificant correlations. The relatively stable urbanized watershed of Grenadier presents limited opportunity for reductions in nutrient loading. The uncoupling of nutrients from phytoplankton suggests that biological manipulations *e.g.* changes in fish or benthic community structure might be more successful as strategies for management of production in Grenadier.

Inorganic nitrogen to total phosphorus ratios in Catfish are also suggestive of nitrogen limitation (3.7). However, plankton nutrient relationships (both nitrogen and phosphorus) in Catfish are significant. Interestingly more variance in chlorophyll is explained by phosphorus but more of the variance in volumetrically determined phytoplankton biomass is explained by total inorganic nitrogen. Soluble reactive phosphorus levels are substantially lower in Catfish (7.6%) compared to Grenadier and on 2 occasions are below limits of detection suggesting that phosphorus may be the limiting nutrient in Catfish; alternatively blue-green algae do dominate the plankton community for cycles 5 - 8. Organic nitrogen:organic carbon ratio is higher in Catfish than Grenadier (3.9 versus 3.3) and somewhat suggestive of nutrient status but without tissue nutrient analysis it is impossible to determine whether phosphorus or nitrogen is the primary limiting nutrient in Catfish. If nutrient management strategies are to be implemented additionally nutrient analyses, plankton tissue analyses and perhaps limno corral nutrient reduction experiments are warranted.

5.8.3. Water Column Heavy Metals

Heavy metals analyzed in the water column of Catfish and Grenadier were cadmium, chromium, copper, lead, zinc and mercury. Only copper exceeded government guidelines (MOE 1984) Table 5.8.3. We have no explanations for the high copper concentrations. There are, to the best of our knowledge, no industries located near to the ponds which use copper or produce it as a by-product in significant quantities unless material is being illicitly dumped. Another possibility may be use of copper containing algicides or molluscicides but we have no data suggesting application of either in the ponds. Concentration data from Lake Huron

Table 5.8.3.: Water Concentrations of Heavy Metals
in Catfish, Grenadier and Lake Huron

System	Cycle	Cadmium mg/L	Chromium mg/L	Copper mg/L	Lead mg/L	Zinc mg/L	Mercury ug/L
Grenadier A	Cycle 1	0.0003	0.003	0.018	0.007	0.007	0.02
	Cycle 11	0.0002*	0.001*	0.012	0.003*	0.010	0.06
Grenadier B	Cycle 1	0.0002	0.002	0.018	0.006	0.005	0.02*
	Cycle 11	0.0002*	0.001	0.010	0.005	0.003	0.10
Catfish Mixolimnion	Cycle 1	0.0002*	0.003	0.011	0.008	0.012	0.02
	Cycle 11	0.0002*	0.002	0.007	0.008	0.012	0.01
Catfish Monimolimnion	Cycle 7	0.0005	0.010	0.027	0.010	0.014	0.02
Lake Huron (1976) (I.J.C. Report ^a) (1976)		<.0002	<.0002	0.0015	<.001	0.002	<.00005
MOE		0.002	0.100	0.005	.005-.025	0.030	0.2
Guidelines (1984)		1	1	1	2	1	3

* indicates actual value is less than reported value

^a International Joint Commission on The Great Lakes

1 unfiltered water sample

2 dependent on alkalinity as CaCO₃

3 filtered water sample

(I.J.C. 1976) are included in Table 5.8.3. for comparison of urbanized to a relatively unurbanized system. Cadmium in Catfish and Grenadier is enriched approximately 1.5 times over Lake Huron, chromium approximately 10 times, copper is approximately 7 times higher in the urban systems, lead is 8 times higher, zinc 6 times higher and mercury 1200 times higher.

There are no major differences between Grenadier and Catfish in terms of heavy metals. Copper concentrations are slightly higher in Grenadier. Zinc concentrations are somewhat more elevated in Catfish. All elements with the exception of mercury are elevated in the monimolimnion of Catfish (Table 5.8.3.).

5.8.4. Sediment Chemistry

5.8.4.1. Sediment Nutrients

Table 5.8.4. lists sediment concentrations of total phosphorus, organic nitrogen and organic carbon.

Table 5.8.4.: Sediment Nutrient Concentrations
in Grenadier and Catfish

Nutrient(mg/g)	Catfish	Grenadier
Total Phosphorus	1.4	0.8
Total Kjeldahl Nitrogen	5.0	5.6
Total Organic Carbon	70.00	61.00

Phosphorus and organic carbon are higher while organic nitrogen is reduced in Catfish compared to Grenadier.

5.8.4.2. Sediment Heavy Metals

Sediment concentrations of heavy metals, as might be expected, are higher than the water concentrations. Table 5.8.5. indicates sediment metal concentrations for Catfish and Grenadier with Lake Huron, shown again for comparison.

In contrast to the water column data cobalt, chromium, mercury and nickel were substantially higher in Lake Huron than in Catfish and Grenadier. Arsenic, cadmium, lead, and zinc were higher in the ponds, copper values were similar between Lake Huron and Grenadier, and slightly elevated in Catfish. Sediment concentrations are always higher in Catfish than in Grenadier.

Table 5.8.5.: Sediment Concentrations of Heavy Metals
in Grenadier, Catfish and Lake Huron
(International Joint Commission, 1976)

Element(ug/g)	Catfish	Grenadier	Lake Huron (1976)
Iron	22000	12000	NA
Manganese	910	600	NA
Aluminum	12000	6100	NA
Arsenic	8.91	8.31	1.1
Cadmium	2.60	1.70	1.4
Cobalt	6.00	3.10	17
Chromium	28.00	18.00	32
Copper	62.00	44.00	32
Mercury	0.19	0.16	0.217
Nickel	22.00	12.00	39
Lead	430	290	49
Zinc	570	260	62

5.8.4.3. Sediment Organics

Grenadier and Catfish sediments were analyzed for Aldrin, A-BHC, B-BHC, G-BHC, A-Chlordane, G-Chlordane, Dieldrin, DMDT, Endosulfan I and II, Endrin, Endosulfan Sulphate, Heptachlorepoide, Heptachlor, Mirex, Oxychlordane, OP-DDT, PCB Total, PP-DDD, PP-DDE, PP-DDT, Hexachlorobenzene. All were below the limit of detection.

5.9. Bacterial Water Quality Indicators

5.9.1. Catfish and Grenadier 1983

Means and medians for four bacterial analyses are presented in Table 5.9.1. For all cases in Grenadier numbers reported are higher at station B. than station A. Fecal coliform (FC) and fecal streptococcus (FS) levels in Catfish are higher than either station in Grenadier. *Pseudomonas aeruginosa* and heterotrophic bacteria in Catfish are higher than station A in Grenadier but not as high as station B.

Table 5.9.1.: Bacterial Analyses:
Means (\bar{x}), Geometric Means (GM)
and Medians (M).

Sampling Site	Variable	FCMF		FSMF		PSAMF		PSAMFB		HB20	
		1	2	1	2	1	2	1	2	3	2
GA	x	20	(3)	8	(1)	--	--	9	(2)	2.4E5	(9)
	GM	15	(3)	--	--	--	--	7	(2)	1.5E5	(9)
	M	8	(11)	5<	(11)	2<	(3)	2<	(11)	2.4E5	(11)
GB	x	350	(4)	94	(2)	54	(5)	5	(4)	5.8E5	(10)
	GM	62	(4)	47	(2)	9	(5)	36	(4)	1.2E5	(10)
	M	28	(11)	5<	(11)	2<	(11)	2<	(11)	6.7E5	(11)
C	x	676	(5)	374	(3)	81	(4)	82	(5)	3.8E5	(10)
	GM	117	(5)	135	(3)	16	(4)	23	(5)	2.9E5	(10)
	M	60<=>	(11)	20<=>	(11)	4	(9)	4	(8)	3.5E5	(11)

A = Fecal Coliform
 B = Fecal Streptococcus
 C = *Pseudomonas aeruginosa*
 D = *Pseudomonas aeruginosa*
 E = Heterotroph 20 ° C
 1 = count/100mL
 2 = (n)
 3 = count/mL

Means (\bar{x}) and GM include only those data points not reported as < (less than reported value) or <=> (approximate result) in Appendix 4. Data reported as > (greater than reported value) were included in the Mean as the reported value.

Analyses for fecal coliform, fecal streptococcus and *Pseudomonas aeruginosa* are used as quantitative indicators of situations where fecal matter in aquatic systems is likely to pose a threat to human health. Both Grenadier and Catfish have high levels of heterotrophic bacteria (indicating high organic loading) but only Catfish represents a "potential health hazard" (a.k.a. fecal coliform geometric mean density for a series of water samples in excess of 100 cells per 100 mL, MOE 1984).

A potential health hazard also exists where *P. aeruginosa* (PSAMF and PSAMFB) can be "enumerated and frequently isolated" (MOE, 1984). PSAMF are found in both Grenadier and Catfish in every cycle. However numbers only appear high in Catfish, numbers in Grenadier are almost always less than 2/100ml.

While fecal streptococci are also indicative of sewage contamination, their numbers are generally combined with the geometric mean fecal coliform count to generate FC/FS ratios as indicators of contamination sources. If the ratio is greater than 4, the sewage sources are likely human, a ratio of less than .7 suggests the source is likely non-human animals. These ratio limits are generally only considered reliable when the FC count is at least 100 cells per decilitre (MOE, 1984).

FC/FS ratios for the summer 1983 data are inconclusive: ratios for both Grenadier and Catfish are between .7 and 4 (1.3 and .9 respectively). Scarce *et al.* (1964) have cited reduced ability for FS in natural systems as compared with FC. If so the FS/FC ratios presented may therefore be artificially high as sampling stations were a considerable distance from outfall sites.

5.9.2. 1982 Watershed Bacterial Sampling

In 1982 the City of Toronto Dept. of Public Works conducted a bacteriological survey of eleven stations on the Grenadier/Catfish pond watershed (Appendix 4). Of the eleven stations tested ten had geometric mean FC levels greater than 100 cells per decilitre (129-6546 FC/100ml); of those ten, two were from pond sites, while the remaining eight were sewer and outlet outfalls. Two sites on the Grenadier watershed had extremely high FC counts: the storm sewer outfall near Bloor street and Clendenan avenue (6546 FC/100ml) and the sewer outfall at the south end of Ellis avenue (2093 FC/100ml). FC were also elevated but FC/FS ratios were never above 4 (general accepted evidence for human fecal contamination). For most sites ratios were below .7 (indicating an animal source of contamination). Analysis of the FC/FS ratio is ambiguous at the Clendenan/Bloor outfall whereas the Ellis avenue location marginally indicates non-animal fecal contamination.

Sewer outfalls in the watershed of Catfish pond had generally lower FC and FS counts than Grenadier, FC/FS values for the two sewer outfalls sampled indicate sewage of non-human animal origin. The structure and age of the sewer systems in Grenadier's watershed suggests

that cross connected sanitary sewers and/or the lack of sanitary capacity when peak rain event runoff, exceeds sanitary sewer capacity are responsible for the high fecal loadings to Grenadier. Reduced fecal loading in Catfish seems reasonable considering the degree to which the sewers in the Catfish watershed were constructed (separating sanitary flow from natural runoff (Elstad, 1983).

5.9.3. Bacterial Loadings and Rainfall

The 1982 and 1983 data suggest that sewage contamination is primarily entering the ponds via storm sewers. There should, therefore, be a relationship between rain events and FC values. This will result from three processes: 1) animal feces being washed into the system 2) overflow of sanitary sewers into storm sewers during peak storm events, and 3) flushing out of organic deposits built up in the sewers during low flow conditions.

Figure 5.9.1. plots the fluctuations of FC concentration and daily rainfall over the collection period for the summer of 1983. While by no means rigorous there is a correspondence evident between daily rainfall and FC count for Grenadier B and Catfish stations. The relationship is not clear for the data from Grenadier A - understandable considering its location relative to inflow sites. Investigation of the relationship between daily rainfall and FC counts for the three stations found that only station Grenadier B displayed a significant correlation between FC and rainfall. The estimator: rainfall less than and equal to 2 days prior to sampling date gave the most significant relationship ($r^2 = 0.72$, $P < 0.01$).

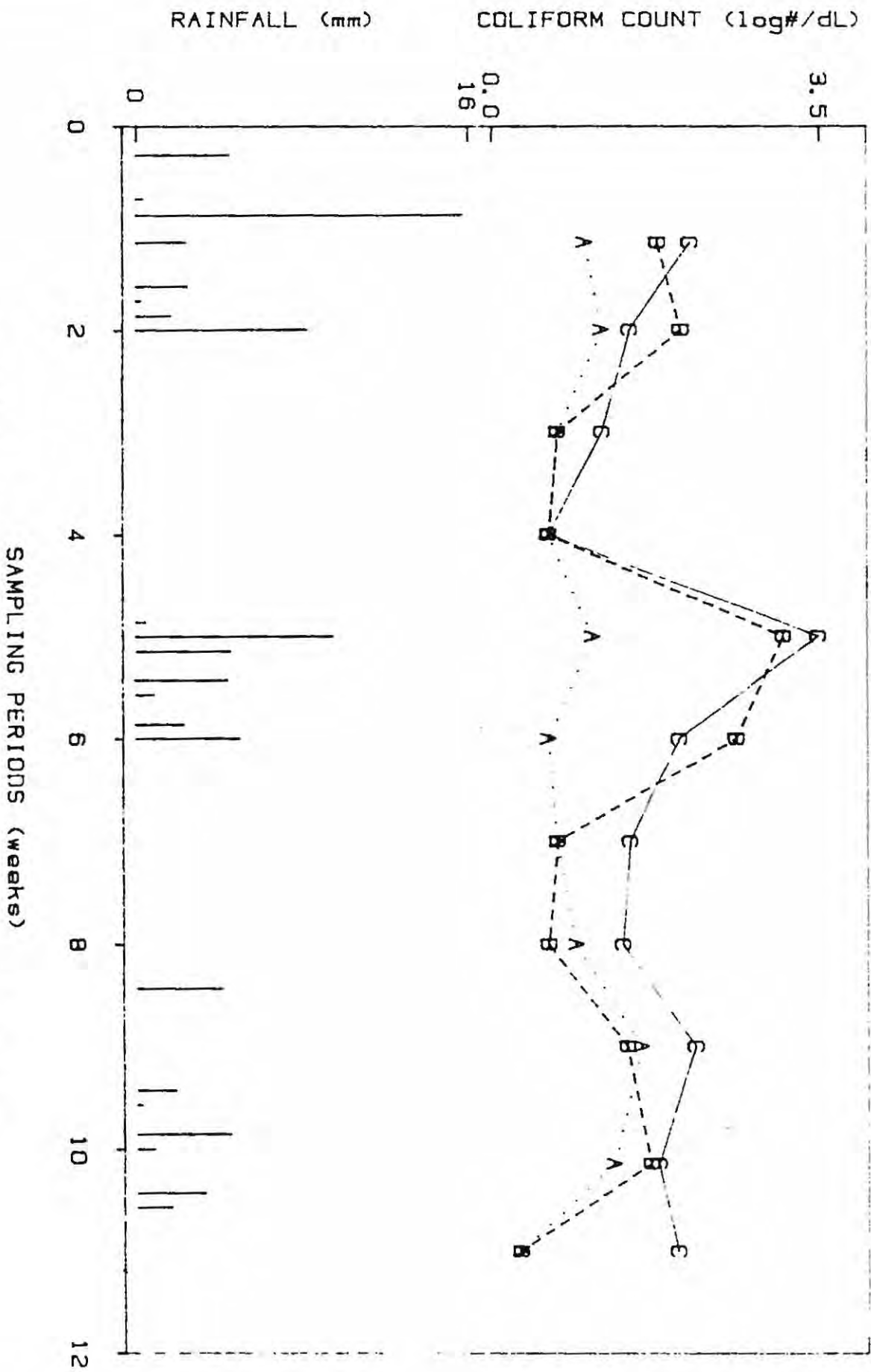


Figure 5.9.1. Fecal coliform counts in Grenadier and Catfish ponds against daily rainfall.
C = Catfish pond, A = Grenadier pond station B - Grenadier pond station A

6. PLANKTON PROCESSES

6.1. Primary Production

In terms of primary production, Grenadier and Catfish are both highly productive systems *i.e.* mean primary productivity $> 125 \text{ mg O}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ (Likens 1975, Wetzel 1983).

Mean areal gross primary production is somewhat higher in Catfish than Grenadier (862 and 766 $\text{mg O}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$, respectively) though net production is higher in Grenadier (Table 6.1.1.).

Table 6.1.1.: Mean Depth Integral of Gross and Net Primary Productivity, Specific Photoassimilation, and Ranges Observed in Net Photosynthesis in Catfish and Grenadier Ponds.

POND	MEAN DEPTH INTEGRAL OF			
	Gross Primary Productivity	Net Primary Productivity	Specific Photoassimilation	Range Observed in Net Photosynthesis
	$\text{mg O}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$	$\text{mg O}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$	$\text{mg O}_2 \cdot (\text{mg CHLa})^{-1} \cdot \text{h}^{-1}$	$\text{mg O}_2 \cdot \text{m}^{-3} \cdot \text{h}^{-1}$
Grenadier	766	473	13.1	30 - 630
Catfish	862	404	8.2	160 - 380

Higher gross production in Catfish is in keeping with its higher phosphorus and nitrogen levels, while its lower net rate of production reflects the higher respiratory costs associated with either the lower light regime or nitrogen fixation (Section 6.4.). Specific photoassimilation ($\text{mg O}_2 (\text{mg CHLa})^{-1} \text{ h}^{-1}$) is also reduced in Catfish over Grenadier.

Reductions in rates of photoassimilation are associated with deterioration in the quality of algal environment (Wright, 1960, Steele and Baird, 1962). For shallow, turbid, nutritionally rich waters the factor often cited in the environmental deterioration is selfshading associated with reductions in PAR (Westlake 1980).

6.1.1. Photosynthetic Profile Development

Phytoplankton are generally expected to photosynthesize to a depth at which approximately 1% of incident light penetrates. For *ex situ* incubation of light dark bottles this depth is approximated by 2X the secchi disk depth.

Phytoplankton are also subject to photoinhibition - a reduction in rate of photosynthesis at high light levels. Consequently, a photosynthetic profile often develops with a reduced rate of productivity at the surface, maximum productivity at some depth x in the water column, gradually attenuating down to the depth of light limitation. This usual scenario is not often found in either Grenadier or Catfish. Photoinhibition is seen in 5 of 11 sampling times in Grenadier, but only on two occasions in Catfish. However, net oxygen evolution is never observed at 2x the secchi depth in either pond and at the 1x secchi depth on only two occasions in Catfish and 5 in Grenadier. There is usually evidence of photosynthetic oxygen generation in these samples since light bottle values are higher than dark bottles (or there is an increased rate of dark respiration). However, neither bottle is as high as the initial oxygen concentration making calculation of production values impossible.

6.1.2. 1976 - 1983 Grenadier Comparisons

Comparisons of productivity values with Wainio *et al.* (1976) are difficult. Wainio cites a Randall (1974) derived value for net primary productivity of $2.62 \text{ mg.O}_2\text{-L.h}^{-1}$. Even assuming the 2.62 figure is the euphotic zone weighted composite, the value translates to $4685 \text{ mg.O}_2\text{-m}^{-2}\text{-h}^{-1}$ (based on 3:1 conversions of Westlake *et al.*, 1980). This is significantly higher than one of the highest spot rates of net primary production ever reported, $745 \text{ mg.O}_2\text{-m}^{-2}\text{-h}^{-1}$ at Smith Hole, Indiana (Wetzel 1973). The full bibliographic citation for Randall (1974) is missing from the Bibliography of Wainio *et al.* (1976). We can find no record of a Randall thesis at the University of Toronto. We feel the reported figure in Wainio *et al.* 1976, is incorrect however we are at a dead end in chasing it down. Subsequently, we can draw no

conclusions as to changes in rates of primary production in Grenadier.

6.1.3. Areal Hypolimnetic Oxygen Deficit

The areal hypolimnetic oxygen deficit (AHOD) was calculated for Grenadier pond following standard methodology except that oxygen profiles rather than thermal profiles were used to estimate the depth of the "hypolimnion". This procedure was done as the pond does not undergo complete thermal profile development due to its shallow basin (Section 4.2.), and therefore the depth at which anoxia occurred was felt to be a more accurate estimation for areal productivity.

Deficits were calculated from the beginning of the sampling period through when mixing entrained some oxygen in the lower waters (Section 5.3.1.). The early summer AHOD was $0.336 \text{ mg O}_2 \text{ cm}^{-2} \text{ days}^{-1}$. By cycle 10, AHOD had increased to $0.866 \text{ mg O}_2 \text{ cm}^{-2} \text{ days}^{-1}$. Average AHOD was $0.601 \text{ mg O}_2 \text{ cm}^{-2} \text{ days}^{-1}$.

The Grenadier AHOD value supports the evidence of a number of other indicators that Grenadier is a highly eutrophied system (Table 6.1.2.).

Table 6.1.2.: Areal Hypolimnetic Oxygen Deficits
($\text{mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$)

LAKE	AHOD	CHL _a ($\mu\text{g/L}$)	Z _n (m)	T _n ($^{\circ}\text{C}$)	SOURCE
Superior	0.04	1.1	125	4.0	a
Georgian Bay	0.024	1.2	25	4.0	a
Ontario	0.125	4.8	70	4.0	a
Central Basin Eric	0.033	5.5	3.3	11.0	a
East Basin Eric	0.061	4.3	13.4	8.0	a
Michigan	0.088	2.3	84	4.0	a
LEWG lakeset (37 lakes)	0.019 range (0.003-0.04)	2.27 range (0.3-7.5)	13.5 range (0-49)	NA	b c
Grenadier	0.601	8.2	3	21.3	

a Charlton, 1980

b Fulthorpe and Paloheimo, 1985

c Zimmerman *et al.*, 1983

Charlton (1980) proposed a model to estimate AHOD based on productivity (Chla), hypolimnion thickness and temperature. The model fits very well for Grenadier, (substituting the thickness of the oxygen defined hypolimnion for the thermally defined hypolimnion). The calculated value was $0.603 \text{ mg O}_2 \text{ cm}^{-2} \text{ days}^{-1}$ which is virtually identical to the average of the two calculated AHODs. The AHOD model was not designed for systems as shallow as Grenadier. We feel the close correspondence of the model to the actual AHOD in the Grenadier system suggests that the majority of production in the system is autochthonous.

Details of calculations can be found in Appendix 6.

The meromictic condition of Catfish renders AHOD calculations impossible for this system.

6.2. Chlorophyll

Chlorophyll concentrations (TOT CHL) are significantly higher in Catfish than in Grenadier, (Table 6.2.1.). Concentrations of chlorophyll per cell ($0.7 \text{ vs. } 0.4 \text{ ng.cell}^{-1}$) are also higher in Catfish. The concentrations of chlorophyll a (CHL_a) and chlorophyll b (CHL_b), the two components of total chlorophyll are also significantly higher in Catfish (Table 6.2.1.). However, the proportions of total chlorophyll attributable to chlorophyll b ($\text{CHL}_b/\text{TOT CHL}$) are not different between the ponds, nor are the percentages of total chlorophyll a that are actually active chlorophyll (as opposed to phaeopigment, $\text{CHL}_a/\text{CHL}_a \text{ PHAO}$) different (Table 6.2.1.).

Table 6.2.1.: Significance Levels for T-tests
For Various Chlorophyll Components
in Catfish and Grenadier Ponds

Chlorophyll Component (ug/L)	POND		p <
	Grenadier	Catfish	
TOT CHL	16.4	38.4	.06
CHL_a	13.4	29.1	.07
CHL_b	3.0	9.3	.05
$\text{CHL}_b/\text{TOT CHL}$	0.18	0.24	.26
$\text{CHL}_a/\text{CHL}_a + \text{PHAO}$	0.18	0.38	.71

6.3. Phytoplankton Biomass

Average mean wet weight volumetric phytoplankton biomass is significantly higher in Catfish than Grenadier (6540 mg.m^{-3} and 3871 mg.m^{-3} respectively).

Table 6.3.1.: T-Test Results for Phytoplankton Communities in Grenadier and Catfish ponds.

Size Class	Mean Abundance (# x10 ⁷ /L)		Standard Deviation		T value
	Grenadier	Catfish	Grenadier	Catfish	
nanno	2.12	6.86	1.02	5.63	2.75*
non-filaments	0.56	0.26	0.89	0.23	1.04NS
filament	0.04	0.07	0.03	0.16	0.77NS
total	2.71	7.22	1.30	5.62	2.59*

* p < 0.05
NS = not significant

Table 6.3.2.: Dominant Algae Classification for the Phytoplankton Communities

Cycle	Grenadier		Catfish	
	Type	Species	Type	Species
1	Diatoms	<i>Fragilaria sp.</i>	Greens	<i>Scenedesmus sp.</i>
2	Diatoms	<i>Fragilaria sp.</i>	Greens	<i>Scenedesmus sp.</i>
3	Diatoms	<i>Fragilaria sp.</i>	Greens	<i>Scenedesmus sp.</i>
4	Diatoms	<i>Fragilaria sp.</i>	Greens	<i>Scenedesmus sp.</i>
5	Diatoms	<i>Fragilaria sp.</i>	Bluegreens	<i>Merismopedium sp.</i>
6	Greens	<i>Hydrodictyon sp.</i>	Bluegreens	<i>Merismopedium sp.</i>
7	Dinoflagellates	<i>Ceratium sp.</i>	Bluegreens	<i>Merismopedium sp.</i>
8	Bluegreens	<i>Merismopedium sp.</i>	Bluegreens	<i>Merismopedium sp.</i>
9	Dinoflagellates	<i>Ceratium sp.</i>	Greens	<i>Chodatella sp.</i> + <i>Closteridium sp.</i>
10	Greens	<i>Hydrodictyon sp.</i>	Greens	<i>Chodatella sp.</i> + <i>Closteridium sp.</i>
11	Bluegreens	<i>Merismopedium sp.</i>	Greens	<i>Chodatella sp.</i>

In terms of volumetric biomass, nanoplankton make up the majority of biomass in both systems, but the percentage of nanoplankton biomass is higher in Catfish (91.8% and 78.2% respectively).

On a number basis, biomass is also significantly higher in Catfish with nanoplankton again dominating both systems (Table 6.3.1.).

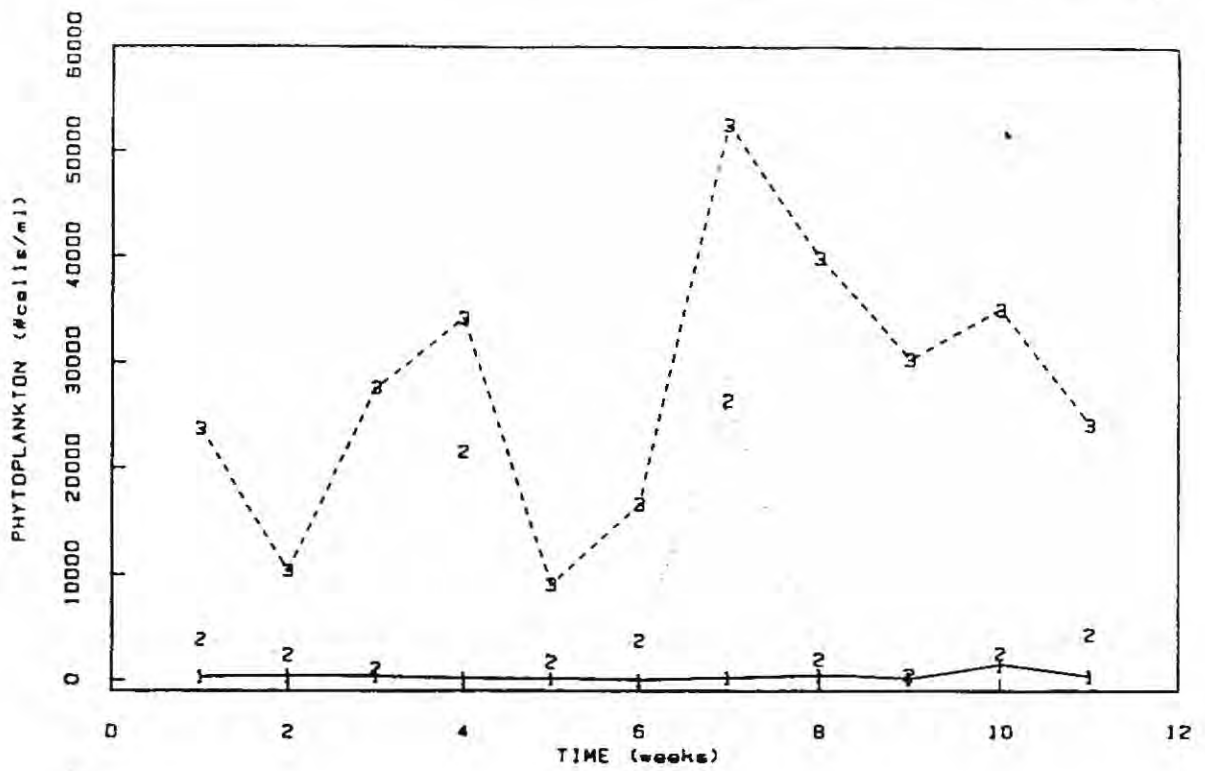


Figure 6.3.1. Phytoplankton size classes: Grenadier pond station A. 1 = filaments, 2 = filaments + netplankton, 3 = filaments + netplankton + nannoplankton.

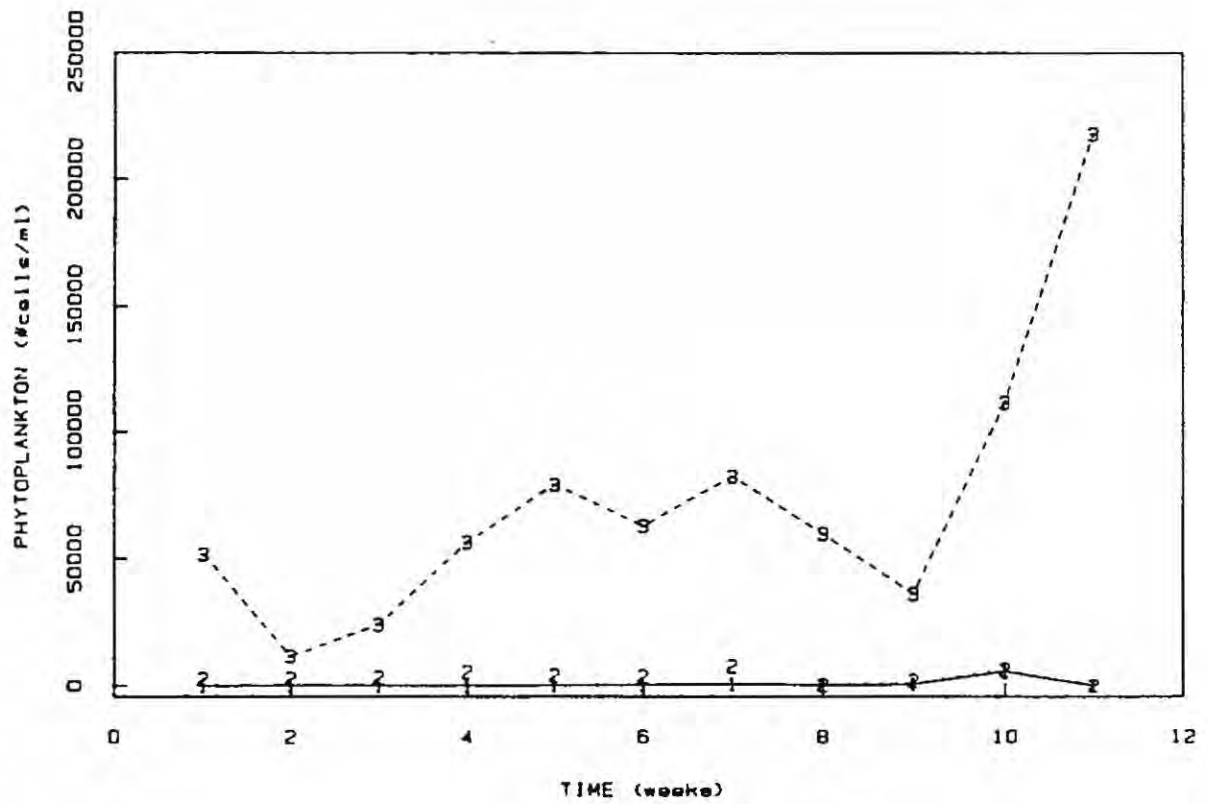


Figure 6.3.2. Phytoplankton size classes: Catfish pond. 1 = filaments, 2 = filaments + netplankton, 3 = filaments + netplankton + nannoplankton.

Cycle by cycle changes in filaments, net and nanno plankton are presented in Figure 6.3.1. for Grenadier. Nannoplankton biomass in Grenadier fluctuates across the summer with 2 biomass peaks in cycles 3 and 8. These fluctuations appear tied to the dynamics of herbivorous zooplankton in Grenadier (Section 6.5.3.). Netplankton also show 2 peaks (cycle 4 and 7) but these fluctuations are unrelated to nannoplankton dynamics.

Cycle by cycle phytoplankton data for Catfish are presented in Figure 6.3.2. Nannoplankton biomass remains relatively constant across the summer until cycle 5, when numbers begin to increase substantially. Maximum biomass occurs in cycle 11 at the end of the summer sampling. Net and filament biomass show little change.

There are taxonomic differences between the communities in the two ponds as well. In Grenadier, the phytoplankton community is dominated by diatoms until midsummer, after that blue-greens, green, and (Pyrrophyta) dinoflagellates fluctuate in and out of dominance on a weekly basis. The phytoplankton in Catfish exhibit a more classic picture: Domination by a monospecific green algae until midsummer, blue-green domination following until late July, after which a different species of green algae dominates. Dominant types and species for both ponds (cycle by cycle) are listed in Table 6.3.2.

6.3.1. Chlorophyll Biomass Productivity Relationships

Brylinsky (1980) has reported significant correlations between phytoplankton biomass, chlorophyll and primary production. Summer averages for Catfish and Grenadier rank similarly for all productivity associated variables except net primary productivity (Catfish with higher gross primary productivity, chlorophyll, volumetric and numeric phytoplankton biomass) Figure 6.3.3. However cycle by cycle regressions between production and chlorophyll a are only significant for Catfish (.82).

Correlation coefficients are higher in Catfish for the relationships between chlorophyll a and primary production, and biomass and primary production but lower than that for biomass and

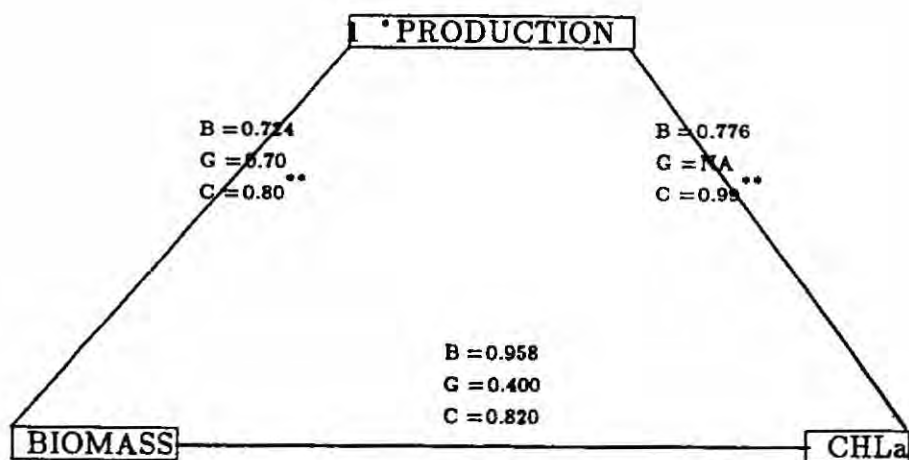


Figure 6.3.3.: Correlations among Primary Production, Biomass and Chla; from Brylinsky (1980) and from Grenadier (G) and (Catfish).

chlorophyll a (Brylinsky's best relationship).

No relationships are significant in Grenadier. Production and biomass relations are strongly size dependent (Paloheimo and Zimmerman 1983, Schlesinger, *et al.*, 1981). We feel the significant relationships in Catfish as compared to Grenadier reflect the higher percentage of phytoplankton biomass (and hence primary production and chlorophyll a) in the nanoplankton size class (91.8).

6.4. Zooplankton

6.4.1. 1983 Zooplankton Biomass

Figure 6.4.1. presents zooplankton biomasses for Catfish and Grenadier. In general, zooplankton biomass is higher in Grenadier with the exception of cycle 3. Values in Grenadier fluctuated about the mean (3213 mg.m^3) for the first four weeks of sampling, reached a

midsummer peak during cycle 6 and subsequently declined throughout the rest of the sampling period. In addition Cladocera (*Bosmina sp.* and *Daphnia sp.*) in Grenadier appear to be more fecund 56% carrying eggs in Grenadier, versus 42.9% in Catfish. Catfish pond zooplankton showed a similar pattern with a maximum peak occurring during cycle 3, followed by a secondary peak in cycle 5 and a subsequent decline throughout the rest of the summer.

During early to midsummer, the zooplankton community in Grenadier pond is dominated by cladocera belonging to either the family Bosminidae or Daphnidae. Copepods dominate for the last three weeks of sampling (Figure 6.4.2.). In Catfish pond, the cladocera dominate the zooplankton assemblage, for the entire summer, far exceeding copepod biomass (Figure 6.4.2.). Table 6.4.1. lists the mean biomass in each taxonomic group for both ponds. Mean Daphnidae biomass for Catfish gives a somewhat distorted picture due to the extremely large numbers during cycle 3 (see Figure 6.4.1.). The total biomass for that cycle was 15783 mgxm^3 , of which 15,722 mg (or 99.6%) was attributed to Daphnidae. Concentrations of Daphnidae were less than this for all other cycles, although Daphnidae constituted on average 71% of zooplankton biomass. A complete species list for both ponds can be found in Table 6.4.2. For trophic analyses to follow (Section 6.5.) all zooplankton species, except *Diacyclops bicuspidatus thomasi* were considered to be filterfeeders or "herbivores". *Diacyclops bicuspidatus thomasi* was classified as a predator or "carnivorous" zooplanktor.

6.4.2. 1983-1976 Comparisons:

6.4.2.1. Taxonomic and Temporal Considerations

Comparisons of the 1983 zooplankton data in Grenadier with that reported by Wainio *et al.* (1976) are somewhat complicated. Apparently no actual data were collected in 1976, the Wainio report presents instead, a re-iteration of data from Rigler (1966). We believe that several errors crept into the 1976 cum 1966 data but it is difficult to verify whether these occurred at the enumeration, calculation, transcription or re-iteration stage of data analyses.

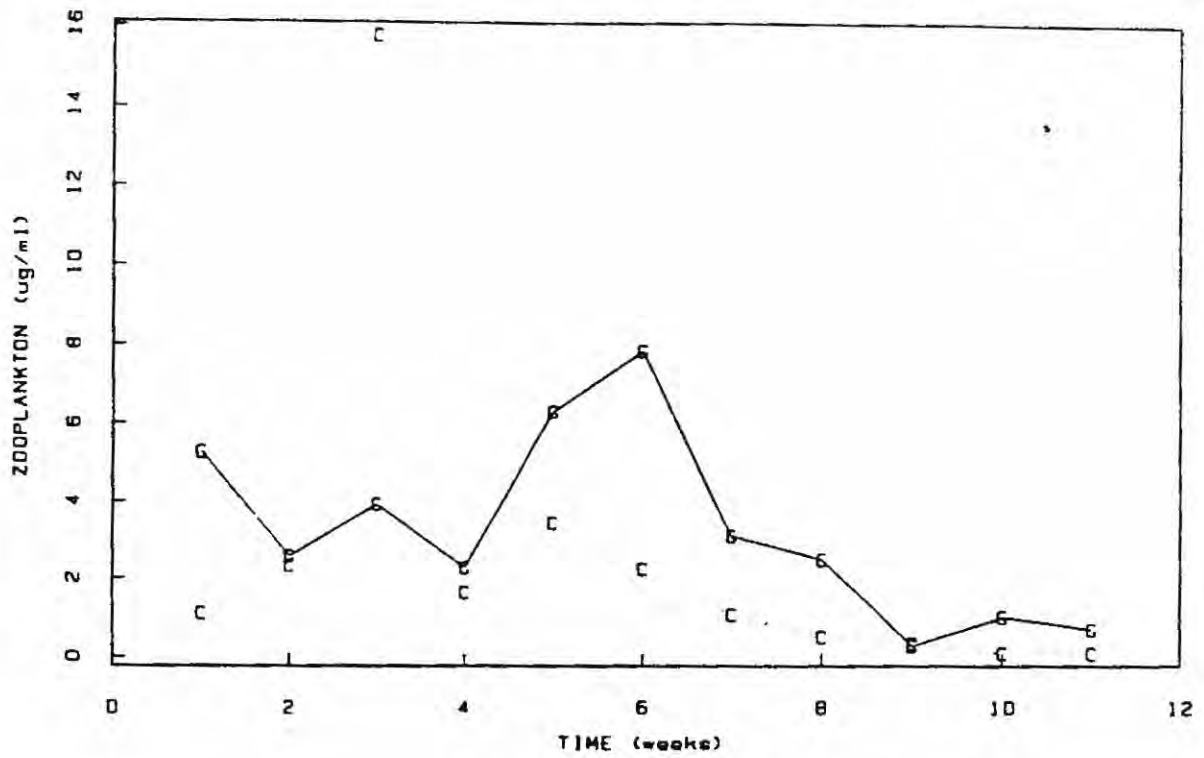


Figure 6.4.1 Total zooplankton biomass, summer 1983.
 G = Grenadier pond station A, C = Catfish pond.

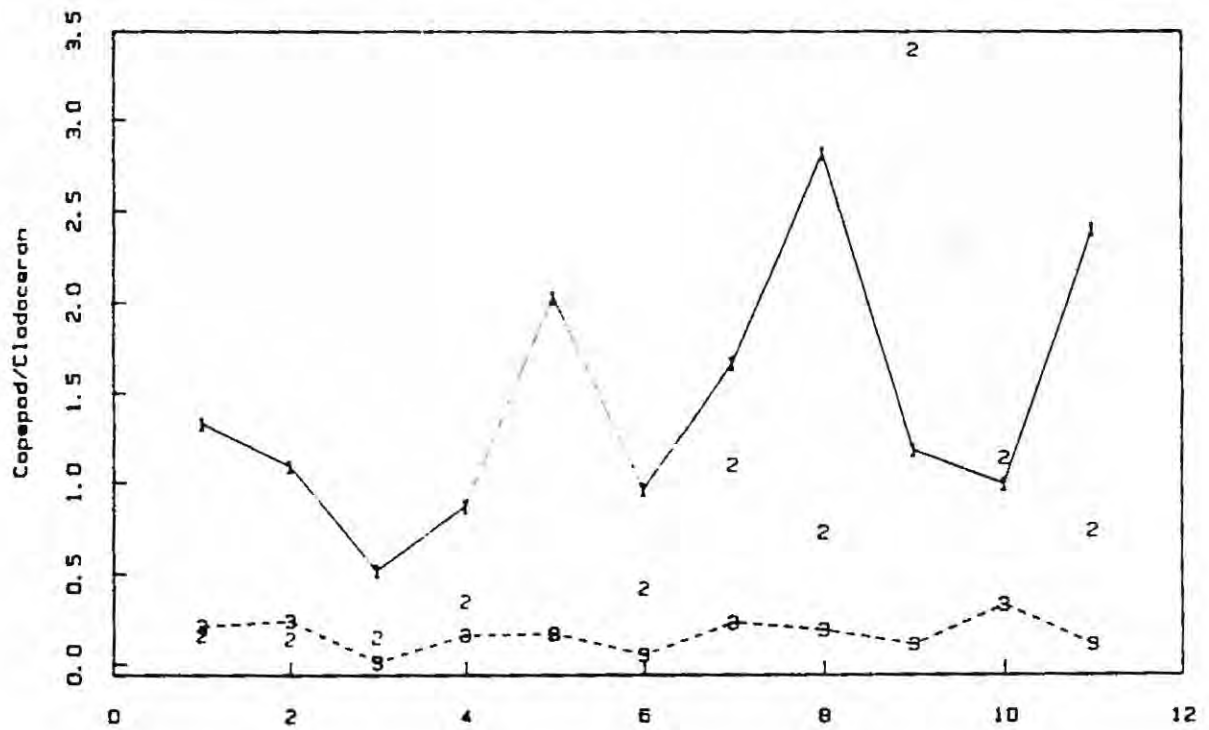


Figure 6.4.2. Copepod:Cladoceran ratios for Grenadier and Catfish ponds 1 = Grenadier pond 1966, 2 = Grenadier pond 1983, 3 = Catfish pond 1983.

Table 6.4.1.: Mean Zooplankton Abundance and Biomass estimates

Pond	Taxa	Abundance		Biomass	
		\bar{x} #/L		\bar{x} mg.m ⁻³	
Grenadier	Cladocera	Daphnidae	40.87	1810.07	
		Bosminidae	25.59	893.09	
	Copepoda	Calanoida	3.43	234.23	
		Cyclopoida	26.79	216.37	
		Nauplii	0.6	1.19	
	Rotifera		4.17	81.27	
	Mean Total.			3213.01	
CATFISH	Cladocera	Daphnidae	39.66	2425.01	
		Bosminidae	10.60	114.99	
		Sididae	0.82	2.99	
	Copepoda	Calanoida	0.03	1.03	
		Cyclopoida	6.36	37.69	
		Nauplii	0.41	0.60	
	Rotifera		1.24	2.49	
Mean Total.			2594.84		

Table 6.4.2.: Zooplankton Species List for Grenadier and Catfish ponds

GROUP	FAMILY	SPECIES
Cladocera	Daphnidae	<i>Daphnia galeata mendotae</i> (Birge)
		<i>D. parvula</i> (Fordyce)
		<i>Ceriodaphnia reticulata</i> (Jurine)*
	Bosminidae	<i>Bosmina longirostris</i> (O.F.Muller)
		<i>Eubosmina coregoni</i> (Baird)
	Sididae	<i>Diaphanosoma leuchtenbergianum</i> (Fischer)*
Copepoda	Cyclopoida	<i>Diacyclops bicuspidatus thomasi</i> (Forbes)
	Calanoida	<i>Diaptomus reighardi</i> (Marsh)
Rotifera	Asplanchnidae	<i>Asplanchna</i> spp.
	Brachionidae	<i>Keratella quadrata</i>
		<i>Kellicottia longispina</i>
* Catfish only		

What were reported as "*Diaphanosoma reighardi*" by Wainio are, we believe, really *Diaptomus reighardi*. *Diaphanosoma* are cladocera while *Diaptomus* are copepods. The species in question is listed with the other copepods and as far as we are aware there is no reighardi species of the genus *Diaphanosoma*. "*Diaphanosoma rosea*", "*Diaphanosoma galeata*", and "*Diaphanosoma* v. *meridotae*" are we believe only two species, *Daphnia rosea* and *Daphnia galeata mendotae* since again there are no known *Diaphanosoma* species by those names. "*Cyclops*

reticulata" is probably *Ceriodaphnia reticulata* since again Cyclops is a copepod while Ceriodaphnia is a cladoceran, the species in question is listed with the other cladocera, and there is no known reticulata species of Cyclops.

A more intractable error occurs either in the totals reported for each species, or in total cladoceran and copepod numbers reported, since unfortunately, these often do not add up and the errors are not systematic. These irregularities make the assessment of whether substantial shifts in either species composition or numbers have occurred in Grenadier since 1976 less rigorous than we would have liked.

Comparing the species list reported by Wainio *et al.*, (1976), corrected as above, with the list compiled in 1983, Table 6.4.2., only two species differences were found. Rigler's 1966 species list included *Daphnia rosea* whereas we found *Daphnia parvula*. In addition *Diaphanosoma sp.* was listed by Rigler, but this genus appears to have disappeared from Grenadier as none were collected in our 1983 samples.

Other differences between 1976 (cum 1966) and 1983 are evident from Table 6.4.3. Using only temporally comparable samples the absolute numbers of copepods have decreased by over 48%. The average number of copepods by 54%. Consequently the Copepod Cladoceran ratio has increased from 1.89 to 2.16. and cladocerans have decreased, but the ratio of the two taxa has remained relatively constant (comparing only similar sampling time spans from the two years and omitting nauplii).

Table 6.4.3.: Mean Concentrations of Cladocera and Copepoda in 1966 and 1983.

Date	Cladocera (\bar{x} #/L)	Copepoda (\bar{x} #/L)	\bar{x} Cop./ \bar{x} Clad.
April-Nov. 1966	74.7	68.1	1.09
May-Aug. 1966	127.3	67.2	1.89
May-Aug. 1983	66.46	30.82	2.16

Mean numbers and relative proportions of copepods and cladocerans broken into Wainio *et al.* categories are listed in Table 6.4.4. As is apparent, the mean numbers are reduced in all taxa in 1983, but the relative proportions of cladocera, primarily Daphnids and Bosminids have increased. Trends in abundance expressed as Copepod/Cladoceran ratio appear reasonably similar between 1966 and 1983 (Figure 6.4.2.).

Table 6.4.4.: Relative Proportions of Zooplankton and Mean Abundances in 1966 and 1983.

Taxa	April-Nov. 1966	May-Aug. 1966	May-Aug. 1983
Abundance (x #/L)			
Cladocera	74.7	127.3	66.5
Copepoda	68.1	67.2	30.82
<i>Daphnia spp.</i>	37.9	67.3	40.9
<i>Bosmina spp.</i>	20.6	37.2	25.6
Total abundance	142.8	194.5	97.3
Relative Proportions (%)			
Cladocera/Total zooplankton	52	65	68
Copepoda/Total zooplankton	48	35	32
<i>Daphnia</i> /Cladocera	51	51	61
<i>Daphnia</i> /Total zooplankton	26	35	42
<i>Bosmina</i> /Cladocera	28	29	39
<i>Bosmina</i> /Total zooplankton	14	13	26
<i>Daph.</i> + <i>Bos.</i> /Total zooplankton	41	53	68

It is difficult to say whether changes in numbers represent significant trophic status changes. The shift in community composition to more smaller sized cladocerans suggests changes in predatory regime. While there may have been changes in fish population structure in Grenadier sufficient to effect changes in zooplankton community size structure, there are few reliable data on fish species composition and no population estimates that we are aware of that would confirm such a hypothesis.

A more plausible alternative seems to be the significant improvement in water clarity that has occurred in Grenadier since 1976 (Section 5.7.4.). Increased water clarity has been shown to enhance reactive distance of visual predators and reduce effectiveness of prey defense strategies (Kitchell and Kitchell 1980). In the Kitchell and Kitchell study, *D. rosea* specifically was eliminated and replaced by the smaller *Bosmina sp.* when lake euphotic zone was

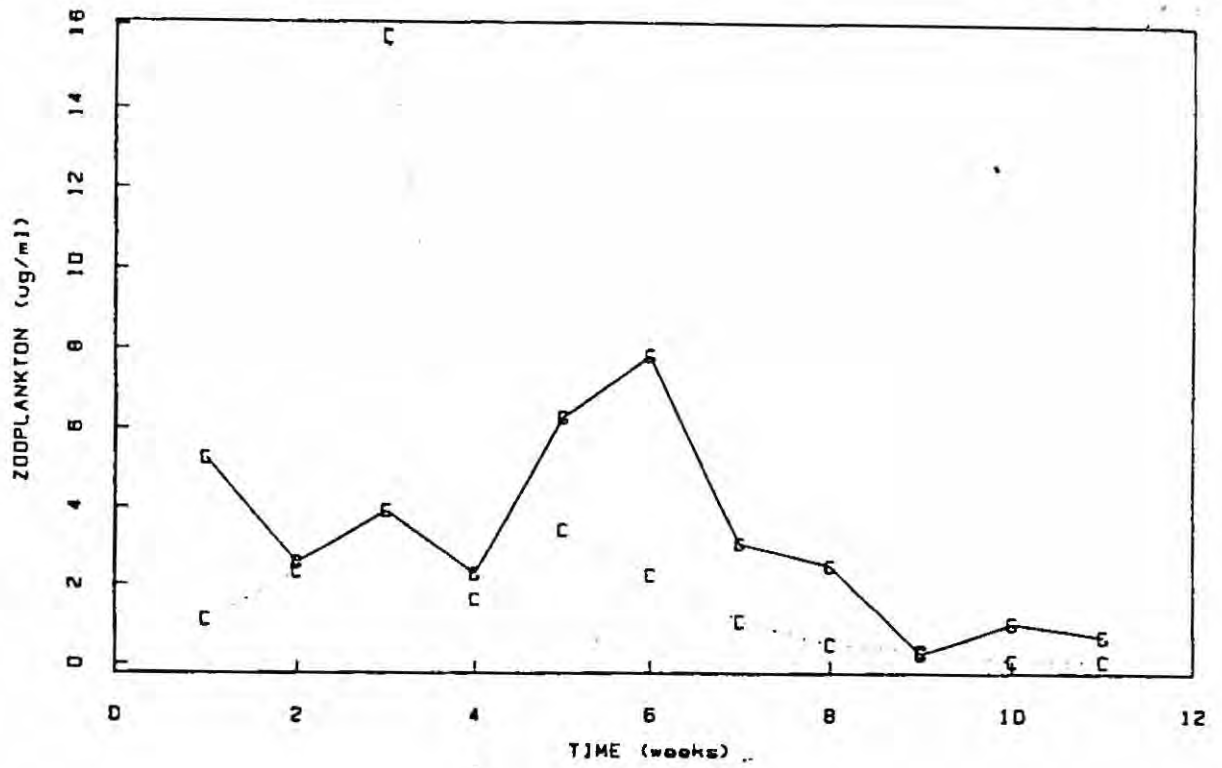


Figure 6.4.1 Total zooplankton biomass, summer 1983.
 G = Grenadier pond station A, C = Catfish pond.

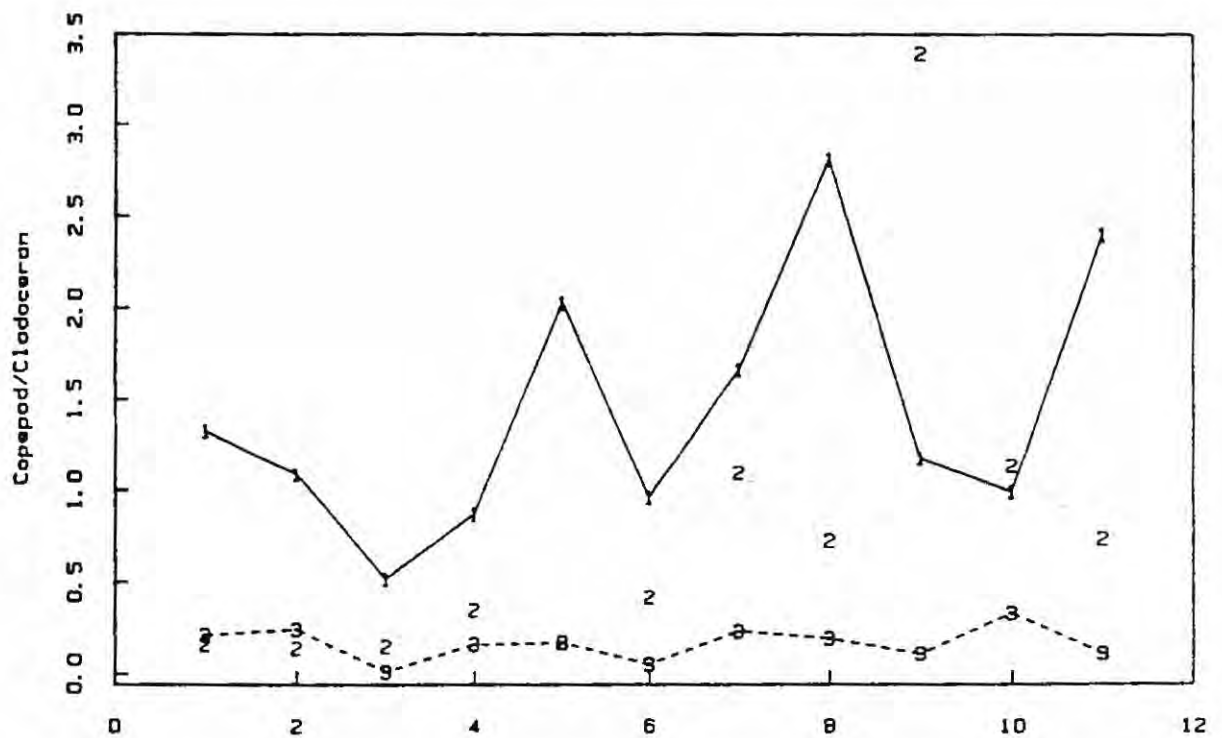


Figure 6.4.2. Copepod:Cladoceran ratios for Grenadier and Catfish ponds 1 = Grenadier pond 1966, 2 = Grenadier pond 1983, 3 = Catfish pond 1983.

increased from 2.7 to 7.0 m. This range compares favorably with the Grenadier Pond increase from 0.7-1 in 1976 to 0.8-4+

If we accept the disappearance of *D. rosea* and its replacement by the smaller *D. parvula*, in Grenadier Pond, the fate of *Diaphanosoma sp.* appears sealed. These latter two species are of similar size and have been identified as potential competitors (Chow-Fraser, 1982). As we will suggest in Section 6.5.3. competition among filterfeeding zooplankton for food is likely to be more intense in Grenadier. If *Diaphanosoma* is the less efficient competitor competitive exclusion of *Diaphanosoma* might be expected.

We find it interesting that *Diaphanosoma* and *D. parvula* co-exist in Catfish; a system for which we have postulated weak to nonexistent competitive interactions between filterfeeders.

6.5. Plankton Dynamics

6.5.1. Density Regulation in Pelagic Systems

Determining the factors that control plankton densities in pelagic ecosystems has been the subject of intense investigation. In terrestrial systems, primary producers are often large relative to the herbivore community with low rates of replacement. In systems sufficiently benign to allow density dependent interspecies relationships, it is generally accepted that the most usual mechanism of density determination is predator control of herbivores (*i.e.* "top down" control) (McQueen, pers.com.). If this were not the case, the theory goes, unchecked herbivore populations would outstrip their food resource and subsequently perish (Hairston *et al.*, 1960). While this scenario does occasionally happen, it is an essentially unstable situation and one that would not be selected for (Odum, 1969).

It was originally suggested that pelagic ecosystems represented the counterpoint to the terrestrial system (Wiegert and Owen, 1971). The primary producers are generally smaller than the herbivore community with higher replacement rates. It was therefore suggested that density

It should be emphasized that these "types" are probably not discrete. The types merely represent set points along a continuum with lakes in between under constantly fluctuating mechanisms of density control. For example, Paloheimo and Zimmerman (1983) found that over a 4 year period, 37% of a group of 19 lakes "typed" by cluster analysis changed categories at least once in that time period while 63% changed categories even more frequently.

There is not as yet any entirely satisfactory paradigm to explain what determines a lake's type. Theoretical systems analyses have suggested that differences in the frequencies of such input variables as light and nutrients will result in communities with radically different biological structures (Webster *et al.*, 1979). Schlesinger *et al.* (1981) demonstrated that the growth rates of large and small sized algae were differentially affected by changing light levels. While both cell sizes showed reduced growth at lower light levels, the smaller cells' growth rate slowed more quickly than that of the larger cells, to the point where both cell sizes were growing at the same rate in low light. Nalewajko *et al.* (1981) showed that algae periodically exposed to limiting levels of light (i.e. those growing in epilimnia that were sufficiently deep to include a zone of <1% incident light) had lower unit productivity than algae in continuous sufficiently lighted epilimnia. She has further demonstrated that small low light adapted algae respond to nutrient inputs differently than large low light adapted algae. Zimmerman *et al.* (1983) suggested that the relative ratio of the euphotic zone to the epilimnia (i.e. sufficiently lighted, >1%, versus partially light limited) was an important predictor for the ratio of nanoplankton to filterfeeding zooplankton.

Table 6.5.1.: Lake Types and Hypothesized Trophic Links and Characteristics

Lake Type	Trophic Links	Characteristics
Topdown iterative	<p>A. Correlations between phytoplankton and nutrients weak.</p> <p>B. Correlations between herbivorous zooplankton and phytoplankton strong.</p> <p>C. Correlations between herbivorous zooplankton and carnivorous zooplankton strong.</p> <p>D. Correlations between zooplankton and planktivorous fish strong.</p> <p>E. Piscivorous fish rare.</p>	
Predation based alternating	<p>A. N or P:nannoplankton correlations weaker (netplankton to nutrients may be stronger).</p> <p>B. Nannoplankton:filterfeeding zooplankton correlations stronger.</p> <p>C. Filterfeeding zooplankton:carnivorous zooplankton correlations weaker.</p> <p>D. Relationship between carnivorous zooplankton and planktivorous fish stronger.</p> <p>E. Relationship between planktivorous fish and piscivorous fish weaker.</p>	<p>1. lakes expected below standard published regression lines for nutrient algal biomass relationships indicating less efficient and underutilization of nutrients by phytoplankton</p> <p>2. mean steady state density of phytoplankton below that theoretically set by nutrient concentrations</p> <p>3. mean steady state density of herbivores higher than resource based alternating</p> <p>4. higher filterfeeding zooplankton:nannoplankton ratios</p> <p>5. "competitive" interactions predominant among herbivores for nannoplankton</p> <p>6. fluctuations in mean steady state density of carnivores uncoupled from herbivores</p> <p>7. decreased importance of detrital pathways</p>

Table 6.5.1. *cont.*: Lake Types and Hypothesized Trophic Links and Characteristics

Lake Type	Trophic Links	Characteristics
Resource based alternating	<p>A. N or P:nannoplankton correlations stronger.</p> <p>B. Nannoplankton:filterfeeding zooplankton correlations weaker.</p> <p>C. Filterfeeding zooplankton:carnivorous zooplankton correlations stronger.</p> <p>D. Relationship between carnivorous zooplankton and planktivorous fish weak.</p> <p>E. Relationship between planktivorous and piscivorous fish strong.</p>	<p>1. lakes expected above standard published regression lines for nutrient algal biomass relationships indicative of a more efficient utilization of nutrients than average</p> <p>2. mean steady state density of phytoplankton at/near maximum theoretically set by nutrient concentrations</p> <p>3. mean steady state density of herbivores lower than predation based alternating</p> <p>4. lower filterfeeding zooplankton:nannoplankton ratios</p> <p>5. "competitive" interactions predominating among phytoplankton for nutrients</p> <p>6. fluctuations in mean steady state density of herbivores relatively independent of nannoplankton, more dependent upon predation pressure from carnivores</p> <p>7. underutilization of primary production in pelagic zone leads to increased importance of detrital pathways (benthic production?)</p>
Bottomup iterative	<p>A. Relationship between nutrients and phytoplankton strong.</p> <p>B. Relationship between phytoplankton and herbivorous zooplankton weak.</p> <p>{ C. and D. Herbivorous and carnivorous zooplankton strongly correlated with planktivorous fish.</p> <p>E. Relationship between planktivorous and piscivorous fish strong.</p>	

6.5.2. Nutrient Status and Plankton Density Regulation

The question of the controls on density regulation is currently of intense interest in limnology. In addition Catfish and Grenadier represent what traditional typology would predict should both be eutrophic systems. In contrast to earlier typologies the lake types we have, described in Table 6.5.1, are far removed from traditional nutrient/trophic based lake typologies. Nutrient states will certainly define the limits within which planktonic trophic dynamics can operate, but there is no evidence that what we have called topdown and bottomup behaviours are exclusively and respectively restricted to oligotrophic or eutrophic lakes (Dalziel, 1985). We have tried to evaluate the dynamics of plankton in Grenadier and Catfish within the protocol of Table 6.5.1. We believe that both systems are alternating as opposed to iterative with Grenadier exhibiting predation based behavior and Catfish demonstrating resource based behaviour. Table 6.5.2. presents some of the pertinent relationships between the ponds. Phosphorus, nitrogen and phytoplankton abundances are higher in Catfish, while zooplankton biomass is higher in Grenadier.

Table 6.5.2.: Mean (\bar{x}) Plankton Values and Nutrient Concentrations for Grenadier and Catfish Ponds.

Variable \bar{x}	Grenadier	Catfish
TP (ug/L)	86.3	125.7
IN (ug/L)	0.38	0.50
nanno (#/L)	2.15×10^7	6.86×10^7
nanno+nct(#/L)	2.68×10^7	7.14×10^7
herbivore(ug/L)	2996.64	2557.00
carnivore(ug/L)	216	37
total zooplankton(ug/L)	3213.01	2594.84
herbivore(#/L)	74	54
carnivore(#/L)	27	8

Table 6.5.3.: Plankton/Nutrient ratios

Pond	#nanno/ug-P	#total phyto/ug-P	#nanno/ug-N	#total phyto/ug-N
Grenadier	0.25	0.08	56.6	71.3
Catfish	0.54	0.57	138.0	144.4

Several relationships derived from Table 6.5.1. are of interest vis-a-vis on trophic protocols and lake behavior. Table 6.5.3. presents the phytoplankton in the ponds as functions of phosphorus and nitrogen. The ratios clearly show that more units of plankton are produced per unit of nutrient in Catfish. A more efficient utilization of available nutrients (point 1) and higher productivity (Section 6.1.) support our contention that the density of phytoplankton in Catfish is closer to the theoretical limit set by nutrients (point 2).

6.5.3. Phytoplankton Density Regulation: Competition Versus Predation

A larger zooplankton community supported by a smaller standing stock of phytoplankton in Grenadier, implies a more efficient energy transfer relative to Catfish. This reduced energy transfer is also apparent at the next trophic level where Grenadier supports 0.36 carnivores/herbivores and Catfish only 0.11 carnivores/herbivore. In terms of biomass, the percentage decrease in Grenadier is 0.93 or a 7% transfer efficiency, close in fact to the theoretical limit of 10%. In Catfish the percentage decrease is 0.986 or only about a 1% herbivore carnivore transfer efficiency.

We would predict from Table 6.5.1. that relationships between nanoplankton and herbivores would be tighter in Grenadier than in Catfish. As Figure 6.5.1. demonstrates, herbivorous zooplankton in Grenadier appear to track the nanoplankton (<30um) populations, mimicking the fluctuations in abundance of their presumed food resource. The relationship is somewhat clouded after cycle 6, when carnivorous zooplankton appear to increase, herbivorous zooplankton decrease, and nanoplankton populations increase dramatically. Towards cycle 11, herbivores increased in abundance as the predacious zooplankton decreased and again the nanoplankton population decreased. (Net plankton (>30um) were not included as filterfeeding zooplankton are not believed to select substantial amounts of plankton greater than 30um. In addition, the abundance of netplankton was extremely low, and no relationships with the other plankton fractions were found).

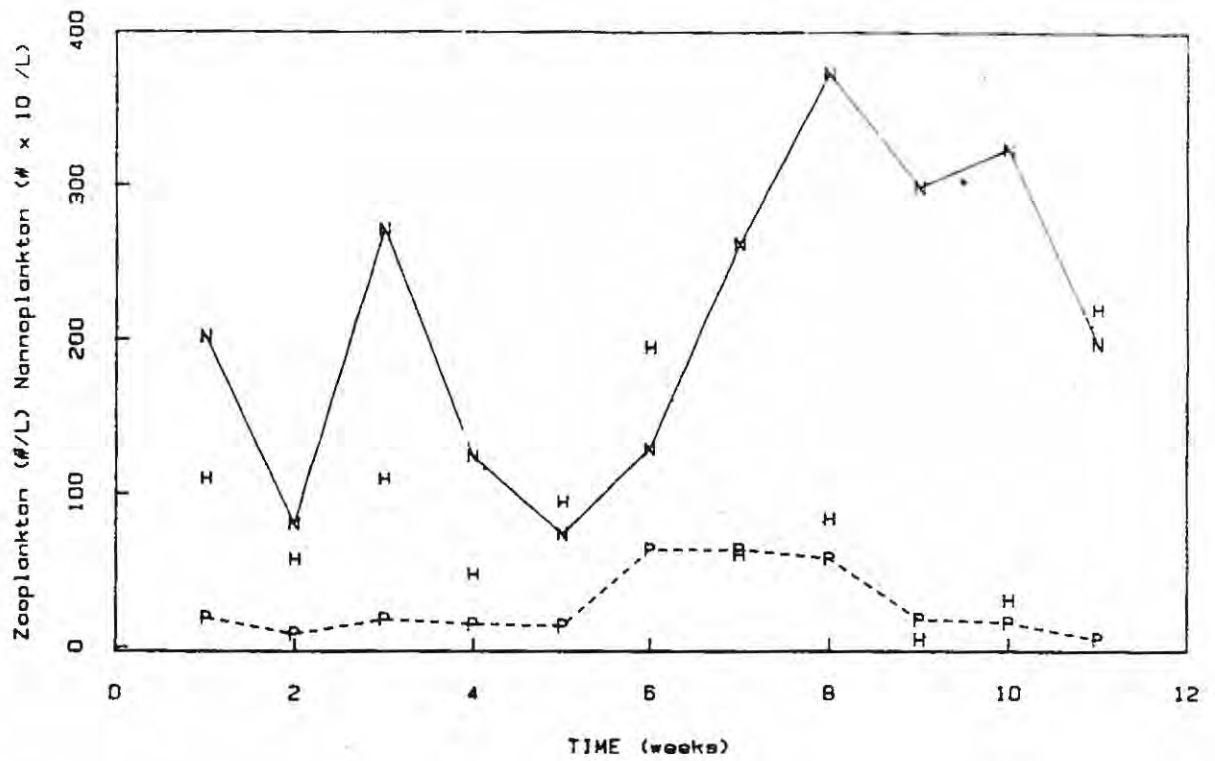


Figure 6.5.1. Plankton abundance: Grenadier pond station A summer 1983. N = Nannoplankton, O = Net plankton, H = Herbivorous Zooplankton, P = Predaceous zooplankton.

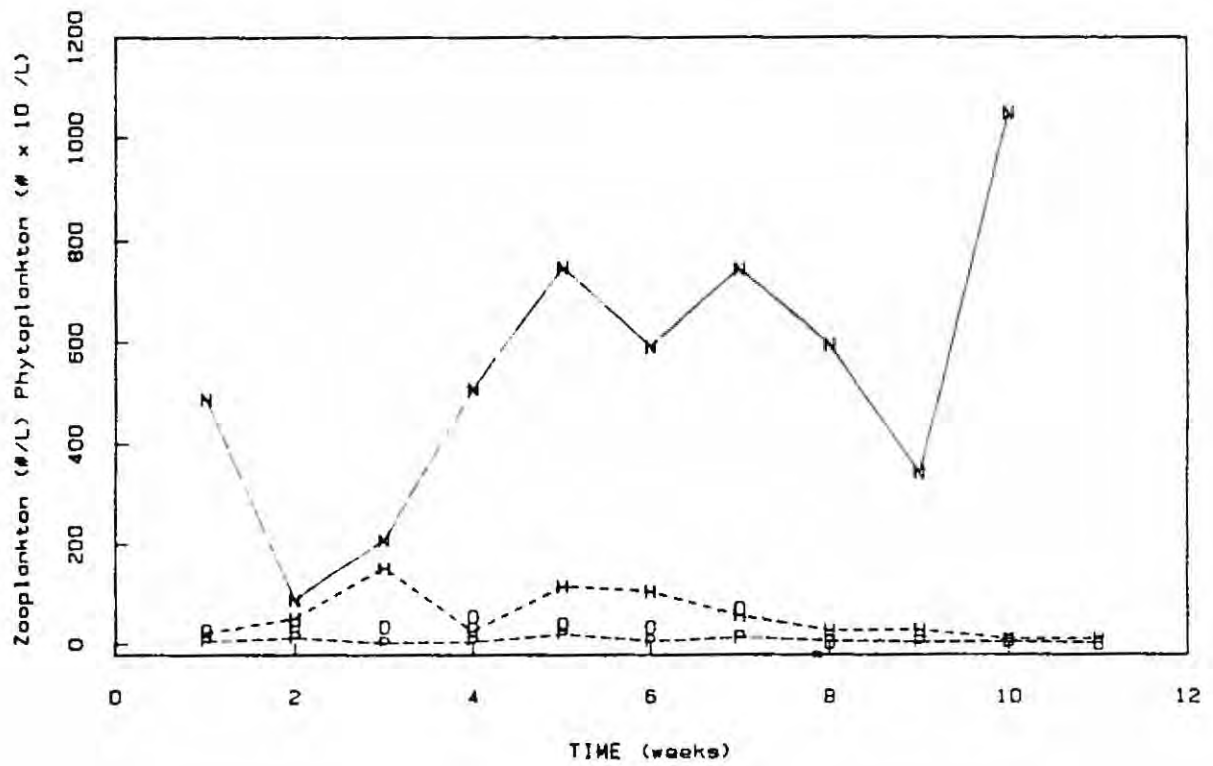


Figure 6.5.2. Plankton abundance: Catfish pond, summer 1983. N = Nannoplankton, O = Net plankton, H = Herbivorous Zooplankton, P = Predaceous zooplankton.

Figure 6.5.2. shows the relationship between nanoplankton, netplankton, herbivorous and carnivorous zooplankton in Catfish. Although there is what appears to be some very early tracking of nanoplankton by herbivores in cycles 2 and 3, the relationship does not continue. Nanoplankton and herbivores seem to fluctuate independently in Catfish.

Figure 6.5.3. expands the relationship between herbivorous and carnivorous zooplankton in both Grenadier and Catfish. There are points of correspondence between herbivores and carnivores in both ponds. Numbers are low so it is difficult to see any trend between herbivores and carnivores. Herbivore populations appear to respond to the cycle 6 increase and cycle 9 decrease of the predatory zooplankton population in Grenadier.

Predators increase a bit in cycles 2 and 5 as herbivores increase in Catfish. However, carnivores remain generally low and do not exhibit strong relationships in either pond.

Table 6.5.4. presents correlation coefficients for various plankton components in Catfish and Grenadier in an attempt to sort out relationships. In Catfish all correlations between phytoplankton assemblages and nutrient concentrations were significant Table 6.5.4. All were higher than any phytoplankton zooplankton correlations in Catfish. All were higher than nutrient phytoplankton correlations in Grenadier as well. This result supports the hypothesis that the major density regulation mechanism in Catfish occurs at the nutrient phytoplankton level, *i.e.* phytoplankton density is a function of resources (nutrients) rather than predation pressure from grazing herbivorous zooplankton.

In Grenadier, we would predict that nanoplankton filterfeeding zooplankton correlations would be stronger than nutrient phytoplankton correlations or nanoplankton filterfeeding zooplankton correlations in Catfish. Both are true (although the nanoplankton nutrient correlation is stronger than the phytoplankton nutrient relations and indeed stronger than nanoplankton filterfeeding zooplankton) however the probabilities associated with those correlations are not high. As Figure 6.5.1. demonstrated, the low probabilities associated with nanoplankton filterfeeding zooplankton correlation probably result from the imposition of the her-

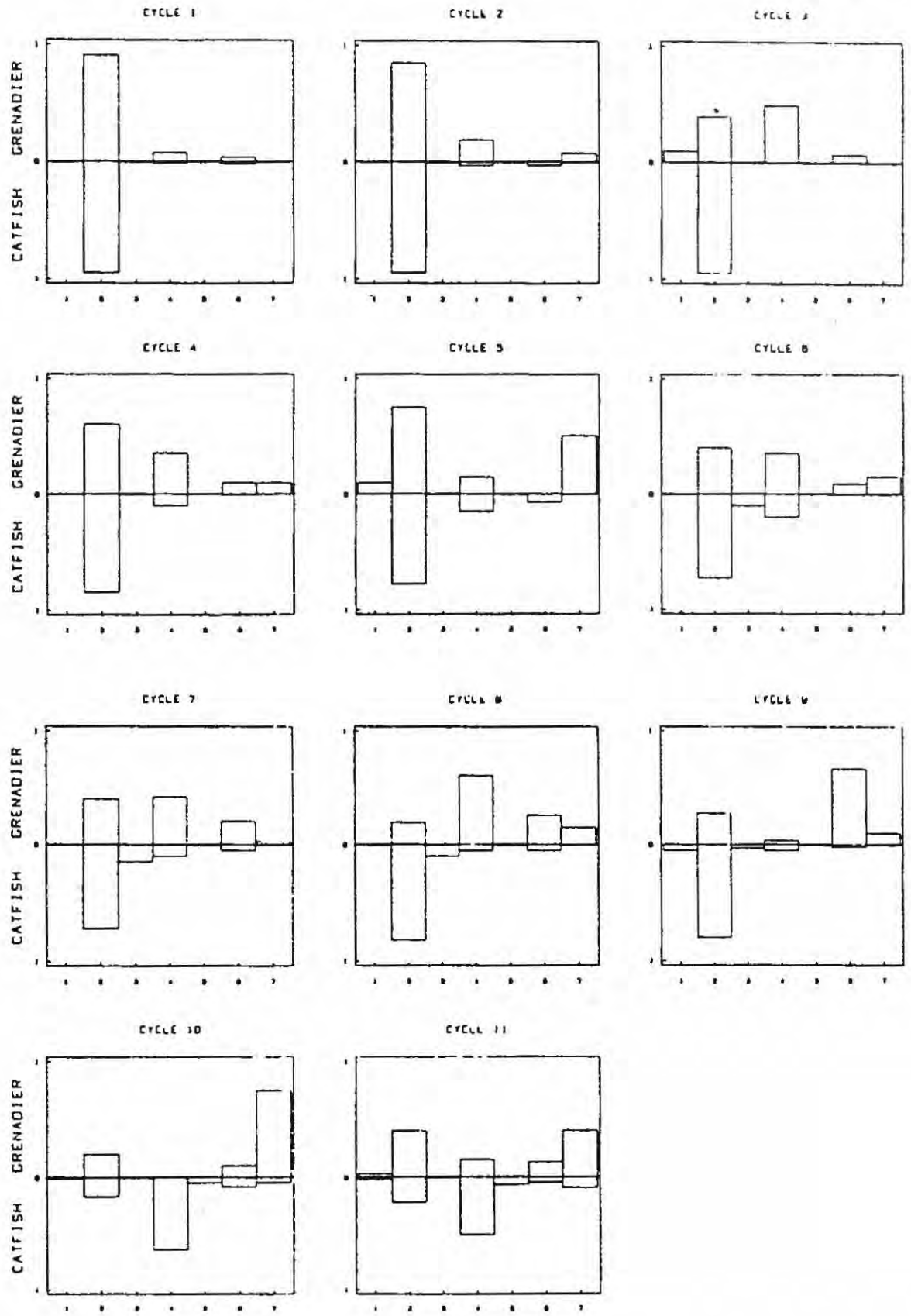


Figure 6.5.3. Cycle by cycle changes in zooplankton proportional biomass for Grenadier and Catfish ponds. Y axis is biomass proportion. X axis: 1= Rotifers, 2=*Daphnia* spp., 3=*Ceriodaphnia*, 4=Bosminids, 5=*Diaphanosoma* sp., 6= *Diacyclops* sp., 7=*Diaptomus* sp.

Table 6.5.4.: Correlation Coefficients For Plankton Relationships for n=11 cycles

Correlation	Grenadier	Catfish
total phosphorus vs. nanoplankton	0.51	0.69*
total phosphorus vs. total phytoplankton	0.33	0.68*
inorganic nitrogen vs. nanoplankton	0.51	0.69*
inorganic nitrogen vs. total phytoplankton	0.30	0.76**
filterfeeding zooplankton vs. filterfeeding zooplankton	-0.46	-0.42
filterfeeding zooplankton vs. carnivorous zooplankton (#/L)	0.18	0.29
filterfeeding zooplankton vs. carnivorous zooplankton (ug/L)	0.22	-0.25
carnivorous zooplankton/ filterfeeding zooplankton vs. nanoplankton	0.51	0.69*
* p < 0.05		
** p < 0.01		

bivore carnivore interaction on the original relationship. When the residuals from the nanoplankton-herbivorous zooplankton are regressed against carnivorous zooplankton, the correlation is significant ($p < 0.05$) and suggests that the variability in the herbivorous zooplankton population not accounted for by the nanoplankton can be attributed to the carnivorous zooplankton population. Therefore we suggest that the major density regulation mechanism in Grenadier, is feeding pressure of herbivores on nanoplankton. This pressure effectively holds phytoplankton populations below the theoretical level set by the nutrient resources available to them (lower yields of phytoplankton per unit phosphorus).

The question remains as to why the nanoplankton community in Catfish appears to be underexploited. Cladoceran zooplankton in Catfish show lower fecundity than those of Grenadier (Section 6.4.1.) and appear incapable of generating a population sufficiently large to

influence nanoplankton population densities. Reduced fecundity is generally associated with quality or quantity. There is an abundance of food quantity. However, there is a reasonable body of circumstantial evidence to suggest that food quality may be impaired in Catfish due to: a.) higher concentrations of bacterial/organic aggregate (Section 5.9.) b) higher respiratory costs in the lower light environment and hence reduced net productivity (Section 6.1.) c) lower protein versus carbohydrate content of algae (Section 5.8.1.) d) higher % blue-green algae. All of these have been shown to influence survivorship and growth rates of Cladocera (Arnold 1971, Gliwicz 1980, Infante 1973, Schindler 1968).

Alternatively it is possible that nanoplankton are not exploited in Catfish due to differences in the impact of either vertebrate or invertebrate predators on the zooplankton community. We do not have sufficient data to adequately test these hypotheses, but circumstantial evidence supports the former contention of reduced nutritional quality of plankton over predation.

Planktivorous fish occur in both ponds. For nanoplankton to be "underexploited" due to vertebrate predation pressure on zooplankton, vertebrate pressure would have to be proportionally more intense in Catfish. There is no evidence to support that contention. For the most part planktivorous fish are visual predators. Light levels are lower in Catfish than Grenadier with the lowest 0.5 m of the mixolimnion sufficiently well oxygenated yet sufficiently dark to serve as a predation refuge for zooplankton. In addition, relative zooplankton body size, an accepted indicator of the presence/absence of visual predation, is larger in Catfish, a situation which argues against a very significant role for vertebrate predation in structuring plankton community relationships.

The larger body size of zooplankton in Catfish could be used as evidence of the importance of invertebrate predation in Catfish. A dark mixolimnion does not constitute a prey refuge from such hydromechanical predators as *Chaoborus spp.* However the anaerobic monimolimnion would limit access to the substrate for *Chaoborus* and we have no evidence that it or any other important large invertebrate predator occurs in Catfish.

Although circumstantial, we believe some aspect of nutritional quality and availability of algae better explains the apparent under-utilization of the nanoplankton in Catfish. The presence of large or unpalatable algae has been shown to decrease the filtering rates of zooplankton independent of nanoplankton concentration.

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APPENDIX 1

Grenadier Pond: Physicochemistry

Cycle by cycle data, 1983

CONDUCTIVITY (umhos/cm)

Grenadier station A

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	1500	1550	1500	1500	NA	1500	1600	1600	1600	1600	1450
0.5	1600	1500	1500	1500	NA	1500	1550	1550	1600	1600	1450
1.0	1600	1500	1500	1550	NA	1500	1550	1550	1600	1600	1450
1.5	1600	1500	1500	1550	NA	1500	1550	1550	1600	1600	1500
2.0	1600	1550	1500	1550	NA	1500	1550	1550	1600	1600	1500
2.5	1600	1550	1500	1550	NA	1500	1550	1550	1600	1600	1450
3.0	1600	1600	1500	1450	NA	1500	1550	1550	1600	1600	1500
3.5	1600	1600	1500	1500	NA	1500	1550	1550	1600	1600	1500
4.0	1600	1600	1500	1500	NA	1500	1500	1550	1600	1600	1500
4.5	1700	1650	1550	1500	NA	1600	1600	1550	1600	1600	1500
5.0	NA	1750	1600	1500	NA	1600	1700	1650	1800	1700	1500
5.5	NA	NA	1600	NA	NA	NA	1850	1700	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	1550	1500	1450	NA	1600	1600	1600	1600	1600	1500
0.5	NA	1550	1500	1500	NA	1600	1600	1600	1600	1600	1500
1.0	NA	1550	1500	1600	NA	1650	1600	1500	600	1600	1550
1.5	NA	1550	1550	NA	NA	1700	1800	NA	1700	1600	1600

DISSOLVED OXYGEN (mg/l)

Grenadier station A

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	14.40	11.2	9.25	NA	10.80	11.6	11.10	10.9	10.4	12.5
0.5	NA	13.60	11.6	9.40	NA	10.60	11.5	10.90	10.5	10.4	12.6
1.0	9.10	13.60	11.0	9.40	NA	10.60	11.4	11.00	9.4	10.2	12.4
1.5	8.55	13.40	11.4	9.50	NA	10.20	10.5	10.90	8.8	10.2	12.2
2.0	8.10	12.80	11.6	9.60	NA	6.00	9.1	6.50	7.8	10.0	11.6
2.5	7.55	11.90	11.3	11.00	NA	4.75	7.5	5.20	7.1	9.6	10.0
3.0	6.60	6.85	10.2	9.40	NA	2.10	4.3	0.90	6.6	9.6	1.7
3.5	6.30	4.00	8.6	8.20	NA	0.20	3.6	0.10	6.0	0.4	0.1
4.0	5.55	1.70	6.6	6.90	NA	0.0	0.9	0.05	5.6	0.1	0.0
4.5	4.10	0.40	1.5	7.20	NA	0.0	0.1	0.05	0.1	0.1	0.0
5.0	3.50	0.40	0.7	3.10	NA	0.0	0.1	0.0	0.0	0.1	0.0
5.5	2.50	NA	0.4	NA	NA	NA	0.1	0.0	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	13.2	12.7	9.6	NA	13.8	13.0	12.4	10.4	11.6	13.5
0.5	NA	13.2	12.2	8.8	NA	13.7	12.8	12.0	10.4	8.2	12.6
1.0	NA	13.1	12.4	10.0	NA	13.0	12.6	8.6	10.8	5.4	10.2
1.5	NA	13.0	12.2	11.4	NA	9.8	4.1	8.1	9.8	4.1	8.1

LIGHT (microeinstains)

Grenadier station A

Depth	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	600	690	1100	1700	2250	1100	2100	1900	2200	2200	2300
0.5	350	500	720	1400	1450	500	1100	920	1600	1100	1700
1.0	200	300	540	1050	1050	280	500	410	910	560	1175
1.5	100	200	380	900	620	160	300	165	360	310	700
2.0	61	120	270	650	430	94	155	90	195	150	410
2.5	38	75	190	450	280	54	63	52	105	100	235
3.0	23.5	75	140	360	155	33	27	26	47	68	145
3.5	15	35	90	250	115	19.5	19	14	26	36	75
4.0	10.5	25	75	175	NA	12	10	3	14	12	42
4.5	5	17	53	115	NA	5	2	0.6	4	1.5	9.1
5.0	5	11.5	35	88	NA	2.1	0.2	NA	0.3	0.1	0.8
5.5	NA	NA	24	NA	NA	NA	0	0	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	47	135	215	160	75	210	190	230	225	220
0.5	NA	26	100	125	87.5	15	100	75	150	80	150
1.0	NA	95	43	49	34.5	8	50	35	86	34	91
1.5	NA	53	27	49	25.5	NA	32	NA	30	20	NA

OXIDATION - REDUCTION POTENTIAL (millivolts)

Grenadier station A

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	230	260	230	215	NA	110	360	190	200	120	300
0.5	238	270	240	215	NA	120	360	190	210	120	300
1.0	240	270	245	215	NA	125	360	190	210	120	320
1.5	245	270	250	220	NA	130	380	190	210	120	320
2.0	250	280	250	220	NA	140	390	205	220	120	340
2.5	250	285	255	220	NA	145	400	210	220	130	350
3.0	255	295	260	220	NA	145	420	210	220	130	380
3.5	265	295	270	225	NA	140	420	30	220	-50	350
4.0	150	180	275	225	NA	-45	150	-100	220	-160	-280
4.5	-30	-100	280	60	NA	-70	-280	-165	-180	-210	-420
5.0	NA	-185	270	-35	NA	-150	-400	-195	-230	-260	-500
5.5	NA	NA	160	NA	NA	NA	-480	-210	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	210	160	180	350	140	120	NA	190	100	140
0.5	NA	210	160	190	350	145	140	NA	190	110	150
1.0	NA	215	140	110	380	150	150	NA	190	120	180
1.5	NA	220	170	NA	370	160	180	NA	200	110	110

pH

Grenadier station A

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	860	840	8.10	8.35	NA	8.90	8.9	8.50	8.3	8.5	820
0.5	860	840	8.10	8.35	NA	8.90	8.9	8.50	8.3	8.5	820
1.0	858	845	8.10	8.35	NA	8.95	8.9	8.50	8.2	8.4	820
1.5	845	845	8.05	8.25	NA	8.95	8.8	8.50	8.1	8.4	820
2.0	835	835	8.10	8.20	NA	8.40	8.7	8.00	8.0	8.4	810
2.5	830	820	8.10	8.15	NA	8.35	8.6	7.95	7.9	8.4	800
3.0	810	795	8.00	7.70	NA	8.05	8.3	7.70	7.9	8.4	750
3.5	790	770	7.85	7.65	NA	8.05	8.2	7.70	7.8	7.6	735
4.0	775	760	7.65	7.55	NA	8.00	7.5	7.35	7.8	7.5	730
4.5	765	755	7.45	7.65	NA	8.05	8.0	7.55	7.5	7.4	720
5.0	NA	750	745	NA	NA	8.10	7.9	7.55	NA	7.4	720
5.5	NA	NA	740	NA	NA	NA	78	7.55	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	81	810	7.95	6.40	9.05	9.0	8.6	8.3	8.3	82
0.5	NA	81	800	7.95	6.35	9.00	9.0	8.3	8.3	8.0	81
1.0	NA	81	805	7.80	6.25	8.75	8.9	7.8	8.3	7.9	76
1.5	NA	81	785	NA	6.30	8.45	8.3	NA	7.7	7.8	74

TEMPERATURE (° C)

Grenadier station A

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	15.8	18.0	22.5	25.0	NA	26.5	23.5	28.0	26.0	25.5	27.5
0.5	15.5	18.0	22.5	24.5	NA	26.5	23.5	27.8	25.5	25.5	27.5
1.0	15.5	18.0	22.0	24.0	NA	26.5	23.5	27.8	24.5	25.5	27.5
1.5	15.4	17.8	21.3	23.0	NA	26.5	23.0	27.5	24.0	25.5	27.0
2.0	15.0	17.5	21.0	23.0	NA	26.0	23.0	26.5	24.0	25.5	26.5
2.5	14.9	16.5	20.0	21.0	NA	25.5	22.5	26.0	24.0	25.5	26.0
3.0	14.5	15.5	18.5	18.5	NA	24.5	22.5	25.0	24.0	25.5	25.0
3.5	14.2	15.0	17.5	16.5	NA	22.5	22.0	23.0	23.5	24.0	24.0
4.0	13.9	14.5	17.0	16.3	NA	21.0	22.0	21.5	23.5	23.0	22.0
4.5	13.7	13.6	16.0	15.5	NA	18.0	20.0	20.0	21.5	22.0	20.5
5.0	NA	13.5	15.0	14.5	NA	16.5	16.5	16.0	17.0	18.0	20.0
5.5	NA	NA	14.5	NA	NA	NA	15.0	16.0	NA	NA	NA

Grenadier station B

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	NA	17.75	23.00	24.8	25	27.75	25.0	28.5	26.5	26.0	28.0
0.5	NA	17.50	22.50	24.6	25	27.75	24.5	28.5	26.5	25.5	27.5
1.0	NA	17.50	22.75	24.0	24	27.75	23.0	26.0	26.0	24.5	27.0
1.5	NA	17.50	22.25	NA	23	27.00	NA	NA	23.5	24.5	26.5

APPENDIX 2

Catfish Pond: Physicochemistry

Cycle by cycle data, 1983

CONDUCTIVITY (umhos/cm)

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	1650	1700	1700	1800	NA	1750	1800	1800	1900	1900	1750
0.5	1650	1700	1700	1800	NA	1750	1800	1800	1900	1900	1750
1.0	1700	1700	1700	1800	NA	1750	1800	1800	1900	1900	1750
1.5	1750	1850	1700	1800	NA	1780	1800	1800	1950	1900	1800
2.0	1900	3000	1800	1850	NA	1850	1800	2000	5500	2100	1900
2.5	4000	15000	4000	4500	NA	4750	5500	5500	15000	7500	4500
3.0	15000	16000	15000	15000	NA	15000	15000	15000	16500	15000	14000
3.5	16000	17500	16000	16500	NA	16500	16500	16500	NA	16500	16000
4.0	17000	18000	17000	17000	NA	17500	17000	18000	NA	18000	17000

DISSOLVED OXYGEN (mg/l)

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	15.0	10.6	11.8	12.6	NA	16.4	11.0	12.4	12.8	14.4	16.6
0.5	14.9	9.8	11.0	11.7	NA	9.0	10.6	10.0	12.1	14.3	16.5
1.0	14.0	8.6	11.2	11.1	NA	5.9	7.8	6.1	7.0	13.2	11.1
1.5	10.4	4.4	10.0	8.6	NA	0.2	4.9	2.5	2.0	12.3	2.2
2.0	6.0	0.1	6.0	2.1	NA	0.1	1.4	0.1	0.2	0.7	0.2
2.5	0.2	0.1	0.5	0.1	NA	0.1	0.1	0.1	0.2	0.2	0.0
3.0	0.1	0.1	0.0	0.1	NA	0.2	0.1	0.1	0.2	0.1	0.0
3.5	0.1	0.2	0.0	0.2	NA	0.2	0.0	0.2	NA	0.1	0.0
4.0	NA	NA	0.0	0.2	NA	0.1	0.0	0.2	NA	0.1	0.0

LIGHT (microeinsteins)

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	2100	410	1700	1850	1500	650	2300	625	2000	2350	2250
0.5	800	195	650	600	90	170	230	100	220	290	890
1.0	260	83	430	130	11	64	30	15	50	50	280
1.5	70	31	250	40	1	7	3	2	7	7.5	45
2.0	15	9.5	120	17	0.5	0.9	0.2	0.1	0.3	0.4	5.5
2.5	14	7	18	2.8	0.1	0.1	0	0	0	0	0
3.0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	NA	0	0
4.0	NA	NA	0	0	0	0	0	0	NA	0	0

OXIDATION - REDUCTION POTENTIAL (millivolts)

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	230	450	500	280	NA	290	275	290	230	320	195
0.5	235	450	520	285	NA	310	280	300	235	320	205
1.0	239	470	520	290	NA	325	290	305	250	320	220
1.5	250	500	550	295	NA	63	300	315	255	325	230
2.0	260	-160	600	310	NA	-90	295	-80	-180	-185	-80
2.5	-70	-420	450	145	NA	-150	-130	-140	-200	-210	-180
3.0	-180	-480	-30	-170	NA	-180	-170	-175	-210	-225	-210
3.5	-220	-520	-380	-210	NA	-215	-190	-200	NA	-235	-220
4.0	NA	NA	-380	-215	NA	-220	-195	-205	NA	-240	-220

pH

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	845	83	8.1	8.50	NA	8.90	8.60	8.70	8.35	8.80	865
0.5	845	85	8.0	8.40	NA	8.40	8.70	8.40	8.50	8.70	865
1.0	840	81	8.0	8.30	NA	8.30	8.50	8.10	8.10	8.70	835
1.5	810	77	7.9	8.10	NA	8.13	8.35	7.80	7.65	8.60	780
2.0	769	74	7.6	7.75	NA	8.10	8.20	7.70	7.20	7.50	750
2.5	710	69	7.2	7.50	NA	7.90	7.75	7.30	7.00	7.25	720
3.0	670	69	6.8	7.25	NA	7.65	7.55	7.15	7.10	7.10	710
3.5	670	69	6.8	7.30	NA	7.70	7.60	7.20	NA	7.15	710
4.0	NA	NA	68	725	NA	7.70	7.65	7.20	NA	7.20	710

TEMPERATURE (° C)

Depth m	Cycle										
	1	2	3	4	5	6	7	8	9	10	11
0.0	15.20	17.5	24.0	24.0	NA	27.3	22.5	27.0	24.5	25.0	28.0
0.5	15.20	17.5	23.5	23.5	NA	26.0	22.0	26.5	24.3	25.0	27.5
1.0	15.10	17.0	22.5	23.5	NA	26.0	21.5	26.0	23.3	25.0	26.5
1.5	14.50	16.0	20.5	23.0	NA	23.5	21.5	25.3	22.5	25.0	25.5
2.0	13.80	13.0	18.0	21.5	NA	20.8	20.5	21.5	18.0	22.0	22.5
2.5	12.00	10.0	14.5	16.5	NA	18.0	17.5	18.0	14.5	18.0	19.5
3.0	10.00	9.0	10.5	11.0	NA	13.5	14.0	14.5	12.0	15.0	15.0
3.5	8.75	8.0	9.0	9.0	NA	10.5	11.0	12.5	NA	12.5	12.5
4.0	NA	NA	8.5	8.5	NA	9.5	10.0	10.3	NA	10.5	11.0

APPENDIX 3

Grenadier pond, 1976: Water Chemistry

from Wainio *et al.*

DATE (1976)	DEPTH (m)	O ₂ mg/L	pH	ALKAL- INITY mg/L	HARD- NESS mg/L	N ₂ mg/L	Fe mg/L	Cu mg/L	Si mg/L	CL mg/L	TEMP. ° C
3/6	0	---	---	---	---	---	---	---	---	---	24.5
	1	---	---	---	---	---	---	---	---	---	24.0
	2	9.6	7.8	270	300	0	0	0.2	---	---	22.5
	3	2.2	---	---	---	---	---	---	---	---	22.5
	4	---	---	---	---	---	---	---	---	---	22.0
	5	0	7.1	390	300	0.3	0.2	0.1	---	---	15.0
	6	---	---	---	---	---	---	---	---	---	13.0
9/6	0	---	---	---	---	---	---	---	---	---	24.0
	1	---	---	---	---	---	---	---	---	---	23.5
	2	9.2	8.0	---	---	0.3	---	---	---	---	22.5
	3	---	---	---	---	---	---	---	---	---	21.5
	4	1.4	7.4	---	---	---	---	---	---	---	16.5
	5	0	7.4	---	---	---	---	---	---	---	14.5
	6	---	---	---	---	---	---	---	---	---	13.5
15/6	0	---	---	---	---	---	---	---	---	---	24.0
	1	12.2	8.2	300	300	0.3	0.1	0.3	---	---	24.0
	2	---	---	---	---	---	---	---	---	---	23.0
	3	2.8	7.4	340	290	0.2	0.1	0.3	---	---	22.0
	4	---	---	---	---	---	---	---	---	---	19.5
	5	0	7.4	410	320	0.5	0.2	0.2	---	---	14.5
	6	---	---	---	---	---	---	---	---	---	13.5
29/6	0	---	---	---	---	---	---	---	---	---	25.0
	1	---	---	---	---	---	---	---	---	---	24.5
	2	10.2	8.5	340	290	0.1	0.2	0.3	3.0	---	24.0
	3	---	---	---	---	---	---	---	---	---	23.5
	4	---	---	---	---	---	---	---	---	---	21.0
	5	---	7.2	---	---	---	---	---	---	---	15.5
	6	---	7.2	---	---	---	---	---	---	---	13.0
5/7	0	---	---	---	---	---	---	---	---	---	24.0
	1	10.6	---	---	---	---	---	---	---	---	23.0
	2	1.2	7.2	200	300	0.2	0.1	0.2	2.3	---	22.3
	3	---	---	---	---	---	---	---	---	---	21.5
	4	---	---	---	---	---	---	---	---	---	21.0
	5	0	---	---	---	---	---	---	---	---	16.0
	6	---	---	---	---	---	---	---	---	---	13.5

WAINIO WATER CHEMISTRY DATA FOR GRENADIER POND 1976

DATE (1976)	DEPTH (m)	O ₂ mg/L	pH	ALKAL- INITY mg/L	HARD- NESS mg/L	N ₂ mg/L	Fe mg/L	Cu mg/L	Si mg/L	CL mg/L	TEMPERATURE °C
13/7	0	---	---	---	---	---	---	---	---	---	22.0
	1	---	---	---	---	---	---	---	---	---	21.5
	2	6.0	7.3	170	300	0.3	0	0.2	4.0	---	21.5
	3	---	---	---	---	---	---	---	---	---	21.5
	4	---	---	---	---	---	---	---	---	---	21.5
	5	4.0	7.6	---	---	---	---	---	---	---	21.2
	6	---	---	---	---	---	---	---	---	---	14.0
19/7	0	---	---	---	---	---	---	---	---	---	23.0
	1	---	---	---	---	---	---	---	---	---	23.0
	2	7.4	8.2	---	---	---	---	---	---	---	22.7
	3	---	---	---	---	---	---	---	---	---	22.0
	4	---	---	---	---	---	---	---	---	---	21.7
	5	2.8	7.2	160	---	0.2	0	0.2	1.9	---	21.5
25/7	0	---	---	---	---	---	---	---	---	---	23.0
	1	---	---	---	---	---	---	---	---	---	22.6
	2	4.6	8.6	---	---	---	---	---	---	---	22.5
	3	---	---	---	---	---	---	---	---	---	22.4
	4	---	---	---	---	---	---	---	---	---	22.1
	5	2.8	7.1	170	---	0	0	0.2	2.5	---	22.0
	6	---	---	---	---	---	---	---	---	---	20.0
2/8	0	---	---	---	---	---	---	---	---	---	23.0
	1	---	---	---	---	---	---	---	---	---	22.5
	2	7.8	8.6	---	---	---	---	---	---	---	22.2
	3	---	---	---	---	---	---	---	---	---	22.0
	4	---	---	---	---	---	---	---	---	---	21.9
	5	5.0	7.0	160	---	---	0.1	0.1	4.0	---	21.8
	6	---	---	---	---	---	---	---	---	---	21.1
11/8	0	---	---	---	---	---	---	---	---	---	22.6
	1	---	---	---	---	---	---	---	---	---	22.5
	2	---	8.4	---	---	---	---	---	---	---	22.4
	3	---	---	---	---	---	---	---	---	---	22.0
	4	---	---	---	---	---	---	---	---	---	21.8
	5	1.0	7.1	160	---	---	0.1	0.1	2.2	350	21.5
	6	---	---	---	---	---	---	---	---	---	21.0

RIGLER WATER TEMPERATURE DATA (° C.), GRENADIER POND 1966

DATE	DEPTH (meters)									
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
16 April	10.0	9.7	9.7	9.2	9.2	8.7	8.3	8.2	8.1	7.3
22 April	12.0	NA	11.8	NA	11.8	NA	11.2	NA	11.1	9.7
2 May	10.6	NA	10.5	NA	10.0	NA	9.9	NA	9.8	9.4
20 May	15.5	NA	15.0	NA	14.5	NA	12.7	NA	10.9	9.7
5 June	21.4	NA	21.1	NA	18.5	NA	16.4	NA	14.8	NA
13 June	21.1	21.1	21.1	21.1	21.1	20.9	19.2	18.8	NA	
20 June	24.2	23.8	23.2	23.2	23.1	21.9	21.0	19.3	NA	NA
28 June	28.1	27.9	28.0	27.8	27.8	24.7	22.4	NA	NA	NA
4 July	29.8	30.3	29.3	29.3	28.9	27.0	24.7	19.8	NA	NA
11 July	25.9	25.8	25.8	25.8	25.8	25.8	24.7	NA	17.5	15.1
19 July	25.7	25.7	25.7	25.7	25.6	25.5	25.4	NA	19.6	14.1
25 July	26.2	26.2	26.3	24.9	24.4	24.0	23.0	NA	19.5	NA
2 August	23.9	23.8	23.9	23.8	23.9	23.8	23.9	NA	20.8	14.6
15 August	23.9	23.6	23.1	23.1	23.0	22.8	22.7	22.6	21.8	16.0
7 September	21.4	21.4	21.4	21.3	21.6	21.4	21.4	NA	20.6	18.1
14 September	18.5	18.5	18.3	18.2	18.0	17.3	17.0	NA	16.9	17.0
19 October	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
3 November	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1

RIGLER WATER OXYGEN CONCENTRATIONS (mg/L), GRENADIER POND, 1966

1966	DEPTH (meters)						
DATE	0.0	1.0	2.0	2.5	3.0	4.0	5.0
28 June	10.99	10.70	6.75	NA	3.64	NA	NA
4 July	8.95	8.95	7.20	2.33	1.21	NA	NA
11 July	7.46	7.32	7.24	NA	6.48	0.00	NA
19 July	8.17	8.11	7.96	NA	6.62	1.29	0.00
25 July	10.12	10.27	6.36	NA	1.99	1.11	NA
8 August	7.95	7.73	7.74	NA	7.45	3.08	0.00
15 August	9.32	NA	8.58	NA	7.33	4.68	0.00
7 September	6.89	6.84	6.82	NA	7.25	0.00	0.00
14 September	8.68	9.61	9.82	NA	5.62	1.38	0.00

APPENDIX 4

1982 WATER QUALITY MONITORING PROGRAM:
 GRENADIER POND AND TRIBUTARIES

STATION LOCATION	GEOMETRIC MEAN (1)		FC/FS RATIO
	FC(2)	FS(3)	
Clendenan Ave. and Bloor St. W (Storm Sewer Outfall)	6546	2021	3.2
Open Creek opposite Valleymede Rd.	731	936	0.8
Inlet at north end of Dacre Cres.	86	476	0.2
Valleymede Rd. and Ellis Park Rd. (Storm Sewer Outfall)	713	804	0.9
N.E. Corner of Rennie Park (Storm Sewer Outfall)	507	1134	0.4
Coe Hill Dr. (Storm Sewer Outfall)	129	219	0.6
Catfish pond Outlet (S.E. corner)	187	491	0.4
Ellis Ave. (Storm Sewer Outfall)	2093	3387	0.6
Outfall from Catfish into Grenadier	217	619	0.4
Grenadier Pond Outlet (S.W. corner)	185	92	2.0
L. Ontario at Outfall W-12	235	381	0.6

- (1) per 100 mL
 (2) Fecal Coliform
 (3) Fecal Streptococcus

APPENDIX 5

**Grenadier and Catfish Ponds:
Primary Productivity Calculations**

Net areal productivity rates were calculated by multiplying the net photosynthetic values (1) derived from the light-dark bottles, by the frustral volume (2) at the depth of incubation for each set of light-dark bottles to determine the mass (3) of oxygen which was then divided by the surface area to give the rate (4) of productivity.

GRENADIER A:

	(1)	(2)	(3)		
Depth of Light-Dark Bottles	Net Photosynthesis	Frustral Volume	Mass	Total Mass	Surface Area
(m)	mg.O ₂ .m ⁻³ .hr	(m ³)	mg.O ₂ .hr	(a+b)*	(m ²)
Surface	\bar{x} 292.5	1.72E5	5.02E7 ^a	1.02E8	1.89E5
Secchi					
Depth					
1.64	200	1.39E5	2.78E7		
1.73	220	1.39E5	3.06E7		
1.99	250	1.39E5	3.47E7		
2.32	450	1.10E5	1.12E8		
			\bar{x} 5.13E7 ^b		

(4): Net Areal Productivity for Grenadier A: 5.37E2 mg.O₂.m⁻².hr.

GRENADIER B:

	(1)	(2)		(3)	
Depth of Light-Dark Bottles	Net Photosynthesis	Frustral Volume	Mass	Total Mass	Surface Area
(m)	mg.O ₂ .m ⁻³ .hr	(m ³)	mg.O ₂ .hr	(a+b)*	(m ²)
Surface	300	1.72E5	5.14E7 ^{*a}	1.05E8	1.89E5
Secchi Depth					
2.04	80	1.39E5			
1.66	200	1.39E5			
1.64	630	1.39E5			
1.73	620	1.39E5			
	\bar{x} 382.5	1.39E5	5.32E7 ^{*b}		

(4): Net Areal Productivity for Grenadier B: 5.56E2 mg.O₂.m⁻².hr.

CATFISH:

	(1)	(2)		(3)	
Depth of Light-Dark Bottles	Net Photosynthesis	Frustral Volume	Mass	Total Mass	Surface Area
(m)	mg.O ₂ .m ⁻³ .hr	(m ³)	mg.O ₂ .hr	(a+b)*	(m ²)
Surface	\bar{x} 235	1.63E4	3.82E6 ^{*a}	8.25E6	2.04E4
Secchi Depth					
0.9	390	1.63E4	6.35E6		
1.8	250	1.00E4	2.51E6		
			\bar{x} 4.43E6 ^{*b}		

(4): Net Areal Productivity for Catfish: 4.04E2 mg.O₂.m⁻².hr.

APPENDIX 6

**Grenadier Pond 1983:
Areal Hypolimnetic Oxygen Deficits (AHOD) Calculations**

Calculations for Cycle 1 - 2:

Hypolimnetic Depth	Cycle 1 [O ₂]	Cycle 2 [O ₂]	[O ₂] ₁₋₂	Frustral Volume	Mass O ₂ At Depth	Total Hypolimnetic O ₂ Mass
	1-	2=	3x	4=	5	Σ 5
(m)	(mg)	(mg)	(mg)	(m ⁻³)	(mg.O ₂ .m ⁻³)	(mg.O ₂ .m ⁻³)
3.5	4.1	4.0	0.1	3.68E4	3.68E3	1.79E5
4.0	3.5	1.7	1.8	7.36E4	1.32E5	
4.5	2.5	0.4	2.1	2.04E4	4.28E4	

The Total Hypolimnetic O₂ Mass (Σ5) was then ÷ by the Hypolimnetic Area (8.85E4 cm²) and the number of days between cycle 1 and cycle 2 (6) to give the AHOD -

$$0.336 \text{ mg.O}_2\text{.cm}^{-2}\text{.day}^{-1}$$

Calculations for Cycle 9 - 10:

Hypolimnetic Depth	Cycle 1 [O ₂]	Cycle 2 [O ₂]	[O ₂] ₁₋₂	Frustral Volume	Mass O ₂ At Depth	Total Hypolimnetic O ₂ Mass
	1-	2=	3x	4=	5	Σ 5
(m)	(mg)	(mg)	(mg)	(m ⁻³)	(mg.O ₂ .m ⁻³)	(mg.O ₂ .m ⁻³)
3.5	6.0	0.4	5.6	3.68E4	2.06E5	6.13E5
4.0	5.6	0.1	5.5	7.36E4	4.05E5	
4.5	0.2	0.1	0.1	2.04E4	2.04E3	

The Total Hypolimnetic O₂ Mass (Σ5) was then ÷ by the Hypolimnetic Area (8.85E4 cm²) and the number of days between cycle 9 and cycle 10 (8) to give the AHOD -

$$0.866 \text{ mg.O}_2\text{.cm}^{-2}\text{.day}^{-1}$$

Mean Areal Hypolimnetic Oxygen Deficit for the entire sampling period: 0.601 mg.O₂.cm⁻².day⁻¹.

Calculations of AHOD using Charlton's (1980) model for Grenadier.

$$(1) \text{ AHOD} = 3.8 \left\{ (f\text{Chla}) \left(\bar{z}_H / 50 + \bar{z}_H \right) \left(2^{[(T_H - 4) / 10]} \right) \right\} + 0.12$$

where : \bar{z}_H = mean hypolimnion depth = 3m

T_H = mean hypolimnetic temperature = 21.3° C.

$$f\text{Chla} = \frac{1.15 (\text{Chla})^{1.33}}{9 + 1.15 (\text{Chla})^{1.33}}$$

The AHOD calculated for Grenadier pond from this model was:

$$0.603 \text{ mg.O}_2\text{.cm}^{-2}\text{.day}^{-1}.$$

APPENDIX 7

1983 ZOOPLANKTON DATA

GRENADIER POND

TAXA	SAMPLING DATE (day/month)										
	31/6	6/6	13/6	20/6	28/6	4/7	11/7	18/7	25/7	2/8	8/8
Bosminids	5.0	7.3	42.6	21.7	17.7	89.4	27.5	60.6	1.2	1.5	7.0
Daphnids	105.1	48.6	40.8	22.7	62.6	91.7	30.3	19.4	3.2	13.6	11.5
Cyclopoids	18.2	7.7	16.9	14.2	12.6	62.9	63.5	57.0	16.6	14.6	10.9
Diaptomids	0.0	0.8	0.4	1.5	4.0	12.9	1.2	3.6	0.4	9.6	3.3
Rotifers	0.0	0.4	25.0	1.0	11.1	2.3	0.0	0.0	0.8	5.0	0.6
Nauplii	0.0	0.0	0.7	0.5	2.0	0.0	0.0	2.4	0.4	0.5	0.0
<i>Ceriodaphnia sp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Diaphanosoma sp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CATFISH POND

TAXA	SAMPLING DATE (day/month)										
	31/6	6/6	13/6	20/6	28/6	4/7	11/7	18/7	25/7	2/8	8/8
Bosminids	1.7	1.7	2.4	6.8	32.3	31.8	17.7	4.9	4.2	7.1	5.9
Daphnids	20.7	49.1	147.9	17.8	58.6	61.6	31.3	18.2	11.4	1.0	0.7
Cyclopoids	4.6	12.1	0.8	3.6	19.2	4.6	13.1	4.9	2.7	3.3	1.1
Diaptomids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Rotifers	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	10.2	0.8	2.2
Nauplii	1.0	0.6	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.1	0.2
<i>Ceriodaphnia sp.</i>	0.0	0.0	0.0	0.0	0.5	8.1	6.1	2.6	0.8	0.0	0.0
<i>Diaphanosoma sp.</i>	0.0	0.0	0.0	0.0	2.5	2.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 8

Grenadier and Catfish Ponds:

Cycle by cycle nutrient data, 1983

SITE	Cycle	Mg mg/L	Na mg/L	K mg/L	SO ₄ mg/L	Si mg/L	Fe mg/L	Mn mg/L
GRENADIER A	1	21.5	178	3.50	72.35	1.11	0.130	0.043
	2	*	*	*	*	1.26	*	*
	3	21.6	190	3.66	70.00	1.34	0.195	0.051
	4	*	*	*	*	0.02<W	*	*
	5	23.1	*	3.70	5.01	3.22	0.210	0.099
	6	*	*	*	*	3.56	*	*
	7	22.3	168	3.70	72.15	4.44	0.100	0.145
	8	*	*	*	*	4.16	*	*
	9	23.0	173	3.66	74.00	3.95	0.055	0.139
	10	23.9	177	3.60	70.80	3.86	0.065	0.124
	11	23.6	173	3.94	70.29	3.81	0.030<T	0.134
GRENADIER B	1	20.6	174	3.38	71.85	1.31	0.150	0.062
	2	*	*	*	*	1.29	*	*
	3	23.2	181	3.76	74.94	1.13	0.280	0.090
	4	*	*	*	*	2.30	*	*
	5	21.0	175	3.56	70.15	3.62	0.195	0.067
	6	*	*	*	*	3.38	*	*
	7	22.4	179	3.60	74.10	3.68	0.130	0.073
	8	*	*	*	*	3.45	*	*
	9	23.7	173	3.60	76.80	3.55	0.135	0.106
	10	24.7	172	3.64	75.10	3.00	0.190	0.056
	11	23.9	181	3.68	72.59	3.31	0.915	0.007
CATFISH MIXOLIMNION	1	27.3	215	14.00	50.53	0.74	0.285	0.109
	2	*	*	*	*	0.85	*	*
	3	27.0	243	15.60	55.00	1.02	0.170	0.090
	4	*	*	*	*	1.62	*	*
	5	28.8	233	16.20	49.25	2.09	0.640	0.212
	6	*	*	*	*	2.35	*	*
	7	30.8	225	17.20	48.21	2.66	0.475	0.155
	8	*	*	*	*	3.00	*	*
	9	31.4	244	19.10	50.71	3.32	0.330	0.190
	10	33.0	242	19.50	50.98	3.22	0.310	0.085
	11	33.0	245	20.70	51.42	3.35	0.460	0.124
CATFISH MONOMOLIMNION	7	35.8	1960	24.90	30.49	6.80	1.400	2.675

POND SITE	Cycle	TOTAL P mg/L	* F.R. P mg/L	KJELDAHL N mg/L	NH ₄ mg/L	TOTAL NO ₃ mg/L	* F.R. NO ₂ mg/L	* F.R. NO ₃ mg/L	DOC mg/L
(1)	1	0.081	0.009	0.58	0.028	0.01<T	0.005	0.005<T	2.9
	2	0.066	0.032	0.92	0.338	0.01<T	0.0085	0.002<T	*
	3	0.037	0.018	0.34	0.278	0.01<T	0.005	0.005<T	3.6
	4	*	0.030	*	0.100	0.40UIN	0.470	*	*
	5	0.087	0.036	0.71	0.218	0.03UIN	0.038UIN	*	2.9
	6	0.113	0.058	0.95	0.570	0.03	0.008	0.017	*
	7	0.092	0.060	0.85	0.296	0.015<T	0.012	0.003<T	3.0
	8	0.138	0.083	1.19	0.450	0.11UIN	0.146UIN	*	*
	9	0.111	0.057	1.15	0.260	0.40UIN	0.475UIN	*	3.0
	10	0.091	0.033	0.92	0.350	0.03	0.021	0.005<T	2.7
	11	0.047	0.008	0.72	0.196	0.01<T	0.008	0.005<T	3.1
(2)	1	0.078	0.008	0.57	0.204	0.04	0.011	0.029	2.9
	2	0.066	0.031	0.90	0.320	0.01<T	0.005	0.005<T	*
	3	0.089	0.024	0.82	0.276	0.04	0.018	0.018	3.2
	4	0.103	0.054	0.93	0.440	0.07	0.037	0.028	*
	5	0.163	0.096	1.59	0.680	0.08	0.015	0.065	3.4
	6	0.124	0.066	1.23	0.500	0.005<T	0.004	0.002<T	*
	7	0.070	0.025	0.77	0.162	0.005<T	0.002	0.003<T	2.8
	8	0.064	0.011	0.75	0.126	0.02	0.006	0.009<T	*
	9	0.072	0.020	0.81	0.212	0.005<T	0.002	0.005<T	3.0
	10	0.063	0.020	0.80	0.264	0.04	0.008	0.028	2.9
	11	0.066	0.018	1.00	0.352	0.01<T	0.003	0.007<T	3.2
(3)	1	0.104	0.007	0.88	0.368	0.25	0.043	0.207	4.2
	2	0.058	0.022	1.00	0.236	0.25	0.181	0.064	*
	3	0.023	0.0005<W	0.38	0.190	0.22	0.034	0.186	4.9
	4	0.131	0.001<T	1.27	0.268	0.23	0.223	0.002<T	*
	5	0.200	0.022	1.75	0.510	0.74	0.705	0.030	5.1
	6	0.210	0.001<T	2.20	0.330	0.010<T	0.007	0.004<T	*
	7	0.143	0.003	1.98	0.244	0.005<T	0.003	0.003<T	5.4
	8	0.177	0.029	2.02	0.550	0.22	0.0005<W	0.220	*
	9	0.150	0.003	1.95	0.294	0.01<T	0.004	0.006<T	5.7
	10	0.126	0.005	1.71	0.252	0.01<T	0.005	0.006<T	5.9
	11	0.061	0.003	0.54	0.212	0.02	0.015	0.006<T	7.5
(4)	7	4.58	3.700	37.00	35.000	*	0.016	*	7.5

LEGEND:

(1) Grenadier A

(2) Grenadier B

(3) Catfish mixolimnion

(4) Catfish monimolimnion

* F.R. - filtered reactive

* Indicates no analysis done for that sample date

<T This low measurement is tentative, for info only

<W "zero" value reported is minimum measurable amount

UIN unreliable; indeterminate interference