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Natural and Anthropogenic Forces Acting on a Forest Lake

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ABSTRACT—Lake Itasca, Minnesota is located within one of the more popular state parks. Since the turn of the century, logging, fire protection, and development within the watershed have put modest pressures on the ecosystem. The presence of the University of Minnesota's Biological and Forestry Station on the lake has encouraged research in this region. Consequently there are numerous research reports and papers which are available at the station's library. We examined data collected over the past 25 years to see if we could detect changes in the lake. We detected no changes in phytoplankton, macrophyte, zooplankton, or zoobenthos communities, but changes have occurred in four species of the fish community—bluegill, walleye, black crappie and northern pike. There is evidence for warmer temperatures during a critical period (May) for most aquatic animals. If true it will affect the biotic interactions to the extent of shifting the equilibrium of the lake.

Introduction

Lake Itasca is not unlike many forest lakes located in northwestern Minnesota. However, because it is the headwaters of the Mississippi River, it is located within one of the more popular state parks. Annually, several thousand visitors enjoy the natural beauty of this area. A sensible concern of those who wish to preserve the beauty of the lake is to ask, "What are the impacts of park activities, and, coupled with natural changes, are these impacts causing the lake to change?" This paper addresses that question.

The Site

Lake Itasca is located in the southern portion of Clearwater and the northern part of Hubbard counties. It is within a natural setting of northern coniferous and deciduous hardwoods. The lake consists of three arms, the west, east, and northern arms. The deepest part is in the east arm at Piece-of-pipe vista, where maximum depth is 14 meters; another hole of 12 m, Siefert's Hole, is found in the north arm. The average depth of 5.2 m indicates that most of the lake is fairly shallow (1). Cole and Underhill (2) classified 55 percent of the total lake area as littoral habitat (<5 m). Summer stratification usually is stable at Piece pipe, but the stratification of shallower portions of the east, west, and north arms may break down during severe summer storms. When stratification is stable, oxygen is depleted in the hypolimnion.

Lake Itasca is moderately productive. Its alkalinity range of 3.1-3.7 meq has not varied between 1964 and 1988. The surface waters of the lake are usually alkaline (pH of 8.0), and conductivity normally ranges between 300 and 350 μs/cm^2. Megard (1) measured gross primary production of 1.24 g C/m^2-day for five dates during the summers of 1965-66. Primary production estimates made by students during the 1970s and 1980s do not differ significantly from this estimate. By most standards the lake would be considered mesotrophic.

Prior to the area becoming a state park in the early 1900s, logging and farming occurred in the area. With establishment of the park, roads, campgrounds, and buildings were constructed. The extent to which the earliest activities affected the lake are unknown, but anthropogenic inputs due to logging and fires could have been significant. In nearby Elk Lake, logging, road building, and other activities of European man affected the lake (3). As in Elk Lake, it is probable that one of the disruptive events affecting the biota of Lake Itasca was the construction of a road and dam over Chambers Creek, which connects Elk and Itasca lakes. Before dam construction by the CCC in the 1930s, the direction of water flow between the two lakes varied, depending on their respective levels. We are uncertain of the early history of this dam, but during the 1960s to mid-1970s the dam was in disrepair. This allowed water to run freely from Elk into Itasca. During this period there was excellent spawning activity by walleye in the gravel bottom of Chambers Creek. In 1979-80 the dam was repaired, and there was silting of Chambers Creek. According to a DNR report (1984 Fisheries Lake Survey) and local observers, this resulted in a decrease in natural spawning of walleye in this creek. An additional factor affecting walleye populations was an increase in fishing pressure during the past two decades.

The major natural factors affecting the basin have been fire and climate. The Itasca region had a continuous history of fires until the arrival of European man (4). After the turn of the century, fire was suppressed, and the forests have not burned for an unusually long period of time. No studies have been conducted on the impact of early fires in the Itasca Basin, but it is doubtful whether they had any long-term impact on the lake ecosystem.

Although long-term temperature records are needed to establish climate trends, it is useful to explore recent trends. The effects of climate change are of local and national concern; is there global climate warming, and, if so, how will this affect our ecosystems? Table 1 shows the air temperatures for the month of May for 1962-1987 recorded at the Biology Station. We have selected May, because this is the month when the ice is normally off the lake, and intense biotic

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activity begins. The rates at which invertebrate populations increase, and fish grow, depend on lake temperature. We have arbitrarily divided the data into two equal time periods, 1962-74 and 1975-87 (Table 1). The most recent 13-year period has been warmer during May than the period 1962-74. All measures of air temperature shown in Table 1 show this difference. Air temperatures during the last week in May have been consistently warmer—a point important to the biota of the lake.

Comparison of Past and Present-Day Communities

Has Lake Itasca been affected by the events of the last 25 years? If so, what has been the magnitude of these changes and how have they manifested themselves throughout the lake ecosystem?

Primary Producers—Phytoplankton and Macrophytes

Although there are numerous taxonomic lists of algae and macrophytes in Lake Itasca, there is a sparsity of quantitative data on the primary producers. David Czarnecki (Pers. Comm., Biology Dept., Loras College, Dubuque, IA.), reports that the phytoplankton of Lake Itasca is typical of glacial lakes of this region, except that it is modified somewhat because of the shallowness of the lake. Generally, chrysophytes (*Mallomonas* and *Synura*), some diatoms, and the blue-green *Aphanizomenon flos-aquae* are found under the ice. During the spring turnover, the chrysophytes continue to flourish, but several species of diatoms (*Asterionella, Cyclotella, Fragilaria, Stepanodiscus,* and *Synedra*) increase in importance. Following the diatoms are species that may persist throughout the summer—several species of *Dinobryon* and green algae, which usually include the conspicuous *Volvox* and later in the summer *Botryococcus.* Blooms of blue-greens during the midsummer are common, with *Oscillatoria* as one of the predominant bloomers.

Table 1. Temperatures recorded by the weather station at Lake Itasca, Minnesota for the month of May, 1962-1987. The last column is average temperatures for the last week in May for these years; this week is important in the phenology of lake biota.

Lake Itasca May Air Temperatures

Year	Average	Average		Heating Degree Days	May 25-31 Ave. Temp.
		Max	Min		
1987	56.8	69.8	43.7	273	72.3
1986	54.3	68.0	40.6	353	81.1
1985	56.2	69.8	42.6	270	67.4
1984	50.0	63.5	36.4	461	66.4
1983	48.8	63.4	34.1	498	65.0
1982	55.6	68.0	43.1	279	73.3
1981	54.3	69.6	39.0	331	66.0
1980	58.8	76.8	40.8	242	84.6
1979	47.6	59.6	35.5	545	71.1
1978	57.5	72.3	42.7	256	74.3
1977	64.6	78.8	50.3	90	79.6
1976	53.6	70.9	36.2	348	73.1
1975	56.1	71.5	40.7	286	72.3
Avg:	54.9	69.4	40.4	325	72.8
1974	49.9	61.7	38.1	467	70.4
1973	53.2	68.5	37.8	358	72.7
1972	57.9	72.8	43.0	257	76.9
1971	51.4	65.4	37.4	423	66.0
1970	50.8	62.4	39.1	440	63.7
1969	54.1	67.2	41.0	359	80.0
1968	51.0	62.8	39.1	427	65.1
1967	45.7	59.6	31.8	590	72.9
1966	47.3	63.0	31.6	545	74.9
1965	52.1	65.5	38.6	397	61.0
1964	55.7	71.8	39.6	306	69.6
1963	55.1	64.0	38.4	319	70.7
1962	51.5	67.8	35.2	420	77.6
Avg:	52.0	65.6	37.7	408	70.9

Submergent macrophytes common to Lake Itasca are *Ceratophyllum demersum* (coontail), *Elodea canadensis* (Canada waterweed), *Myriophyllum exalbescens* (water milfoil), *Najas flexilis* (bushy pondweed), *Utricularia* (bladderwort), and the macroalaga *Chara.* Floating-leaf macrophytes include several species of *Potamogeton* (pondweed) and the waterlilies (*Nuphar* and *Nymphaea*). Near-shore *Zizania aquatica* (wildrice) is very abundant. Interspersed among the rice and extending out to deeper depths is *Scirpus* sp. As mentioned earlier, no quantitative studies on the macrophytes exist, but student and research reports from the Biology Station suggest that this flora has not changed significantly over the past 20 years.

Consumers—Zooplankton

Early reports have listed the same taxa as currently found in the lake, and there is no reason to suspect major shifts in this community. For example, DeCosta (5) published the relative abundance of the littoral *Cladocera,* and the rankings differed little from those published by Whiteside *et al.* (6). There have been no substantial shifts in these assemblages in recent years (Whiteside, unpublished).

A seasonal pattern of community change is apparent for zooplankton. Normally numbers are low during the winter months, except when little snow accumulates on the ice and populations of cladocerans and copepods may then reach summer abundance levels. However, the normal pattern features low numbers during midwinter. As spring approaches, populations of cyclopoid copepods begin to increase under the ice and soon reach their peak numbers. At ice-off the limnetic zooplankton community consists predominately of copepods. As temperatures warm cladocerans (primarily *Daphnia*) increase in relative importance. During exceptionally warm springs, *Daphnia* populations become very abundant, and their grazing causes an increase in lake transparency, resulting in the so-called "clear-water phase" (7). Depending on the severity of larval fish predation on copepods and *Daphnia* (8), this phase may be short-lived or continue into early summer. Typically the numbers of *Daphnia* decline in the limnetic zone during midsummer—probably because of intense fish predation. As summer progresses, smaller-bodied cladocera and copepods remain as limnetic zooplankters, but in reduced numbers. With the onset of fall circulation, the populations of copepods again increase, followed by a drop in their numbers with the onset of winter and snow cover. The littoral zooplankton assemblages follow a pattern similar to that of the limnetic organisms (6, 9, 10).

Consumers—Benthos

Cole and Underhill (2) studied the distribution and abundance of sublittoral and profundal benthos. During the summers of 1987-88, we repeated that study using the same techniques. An Ekman dredge with an area of 233 cm^2 was used to sample at eight depths along a transect in the north arm of Lake Itasca. All animals were screened immediately after collection, and *Chironomus plumosus* was picked out and preserved in 10 percent formalin. Numbers of animals were counted for each depth, and wet weights of preserved animals were determined with a Mettler balance. The results are shown in Figure 1. The results of Cole and Underhill (2) are also plotted in this figure. The recent data suggest greater numbers and biomass of *C. plumosus* than the earlier study at 6 m depth. However, the error terms associated with benthic samples are so large that it is difficult to be confident of these trends.

The pattern of low numbers and biomass in the sublittoral, followed by a rise at intermediate depths, and decreases in these values at 10 m is consistent for both studies (Figure 1). This consistency gives us some confidence that the pattern is real. We believe the shape of these curves is determined by two forces. Predation by fish in the sub-littoral probably keeps chironomid populations low. As oxygen concentrations decline, fish can no longer tolerate stress caused by low oxygen and numbers of chironomids increase. Below 6 meters, concentrations of O_2 fall to less than 1 mg/L (1, and unpublished data), which is below the tolerance limits of fish, but which allows survival of chironomid populations. At 10 meters, O_2 values are very low (<0.2 mg/L), and chironomid assemblages decrease in numbers and biomass (Figure 1). Cole and Underhill reported that the bulk of the benthic biomass consisted of *C. plumosus*; although we did not weight all organisms recovered by the Ekman dredge, it was apparent that the bulk of our samples was *C. plumosus* also.

Consumers—Fish

There are 26 species reported from Lake Itasca (Table 2). The abundances of all species are unknown, but some are obviously rare and restricted to unique habitats (*U. limi*, central mudminnow), while others are very abundant (*P. flavescens*, yellow perch). The major game species taken from Lake Itasca are the northern pike, walleye, black bass, and pan fish—bluegill, pumpkinseed and black crappie. The forage fishes for most of these predators are numerous shiners and minnows, and yellow perch (which makes up a considerable portion of the total fish biomass).

The nature of the fish community has changed somewhat over the past 20 years. This change is reflected in data that has been routinely collected from Lake Itasca by the Minnesota Department of Natural Resources. The Bemidji office of the DNR kindly provided us with "Lake Survey Summaries" for 1960, 1975, and 1984. These summaries have catch per unit (CPU) effort for trap netting, pot nets, and seines. Unfortunately, the seines varied in their mesh-size over the years, so we could not use these data for comparisons, but sampling by pot nets and gill nets was consistent over this period.

Because of the diversity of habitats and the variation in habits, it is very difficult to collect representative samples of the entire fish community. Pot nets are selective for littoral inhabitants, and gill nets for pelagic species, so different taxa are taken by these methods. Therefore the combination of the two methods may not accurately depict the complete nature of the fish community, but they do give information on several game species.

We have extracted data from the DNR summaries for four popular game fish (bluegill, walleye, northern pike and black crappie) that show evidence of change over the past 20 years. Figure 2 plots data for two estimates—total catch and average size. Total catch is a measure of fish biomass expressed in pounds; it was obtained by summing the average weight for gill and pot net catches for each year. Average size is a total catch divided by average number of fish caught. It is evident that the total catch for bluegill and walleye populations has been downward, while northern pike and black crappie catches have increased. The average sizes of bluegill and black crappie have decreased, but for walleye (and perhaps northern pike) there appears to be increases in the average sizes of fish caught between 1960 and 1984.

We believe that real decreases have occurred in walleye and bluegill populations, as expressed by biomass (Figure 2). The heavy fishing pressure and (for walleye) reduced spawning probably have reduced their numbers since 1960. Northern pike have increased in numbers and biomass, potentially in response to fewer walleye, but also because of the difficulty in fishing for them throughout the summer in the weed-choked littoral habitat. Although crappie biomass has increased since 1960, there has been very poor recruit-

Table 2. Fish species collected from Lake Itasca, Minnesota. Sources are J. C. Underhill and J. Hatch.

FISH OF LAKE ITASCA, MINNESOTA

SCIENTIFIC NAME	COMMON NAME
Salmonidae	
Coregonus artedii	Cisco
Umbridae	
Umbra limi	Central mudminnow
Esocidae	
Esox lucius	Northern pike
E. masquinongy[1]	Muskellunge
Cyprinidae	
Notemigonus crysoleucas	Golden shiner
Pimephales notatus	Bluntnose minnow
Notropis atherinoides	Emerald shiner
N. volucellus	Mimic shiner
N. cornutus	Common shiner
N. heterolepis	Blacknose shiner
N. heterodon	Blackchin shiner
Catostomidae	
Catostomus commersoni	White sucker
Ictaluridae	
Ictalurus nubulosus	Brown bullhead
Noturus gyrinus	Tadpole madtom
Cyprinodontidae	
Fundulus diaphanus	Banded killifish
Gasterosteidae	
Culaea inconstans	Brook stickleback
Centrarchidae	
Micropterus salmoides	Largemouth bass
Ambloplites rupestris	Rock bass
Lepomis cyanellus	Green sunfish
L. macrochirus	Bluegill
L. gibbosus	Pumpkinseed
Pomoxis nigromaculatus	Black crappie
Percidae	
Perca flavescens	Yellow perch
Stizostedion vitreum	Walleye
Etheostoma nigrum	Johnny darter
E. exile	Iowa darter

[1] Introduced into Elk Lake by DNR in early 1980s; first caught from Lake Itasca, Summer, 1987.

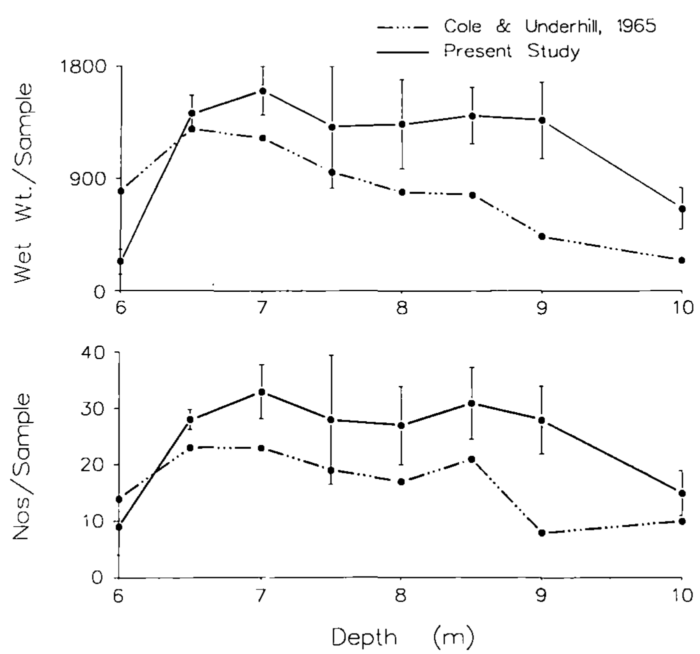

Figure 1. The upper panel shows formalin weights of *Chironomus plumosus* collected during July 1964 (Cole and Underhill, 1965) and July 1987-88 from Lake Itasca, Minnesota. Weights are expressed as mean mg per dredge (233 cm^2) plotted against depth. The lower panel is the mean number of *C. plumosus* collected per dredge plotted against depth for the 1964 and 1987-88 samples. Error bars of one standard deviation are shown for the present study; error terms were not available for the 1964 data.

ment of this species since 1986 (Whiteside, unpublished), and we predict a dramatic decline in the near future.

Discussion

Lakes in equilibrium (i.e., existing under fairly uniform conditions of climate and watershed inputs) normally do not undergo major shifts in their biotic communities. If shifts were to occur, they would have to be initiated by either changes in nutrient inputs, or an alteration of top predators (11). Increased nutrients can stimulate phytoplankton or macrophyte growth, which commonly results in "eutrophication." At the opposite end of the food web, elimination of top predators (piscivores) can cause major changes at lower trophic levels, which are manifested in the appearance of the lake (11). This phenomena has been termed "top down," or "bottom up" control of lake ecosystems (12).

There have been no increases in nutrient inputs into Lake Itasca, and we have observed no "bottom up" effects in the lake; the phytoplankton, macrophytes and zooplankton communities have not changed markedly. On the other hand, there has been heavy fishing pressure of popular game species, especially walleye. We have interpreted the decline in walleye to be the result of heavy fishing pressure coupled with poor recruitment. However, the changes in the fish community have not been of significant magnitude to impact lower trophic levels. There is no evidence of shifts in herbivore (zooplankton) or benthic communities (Figure 1).

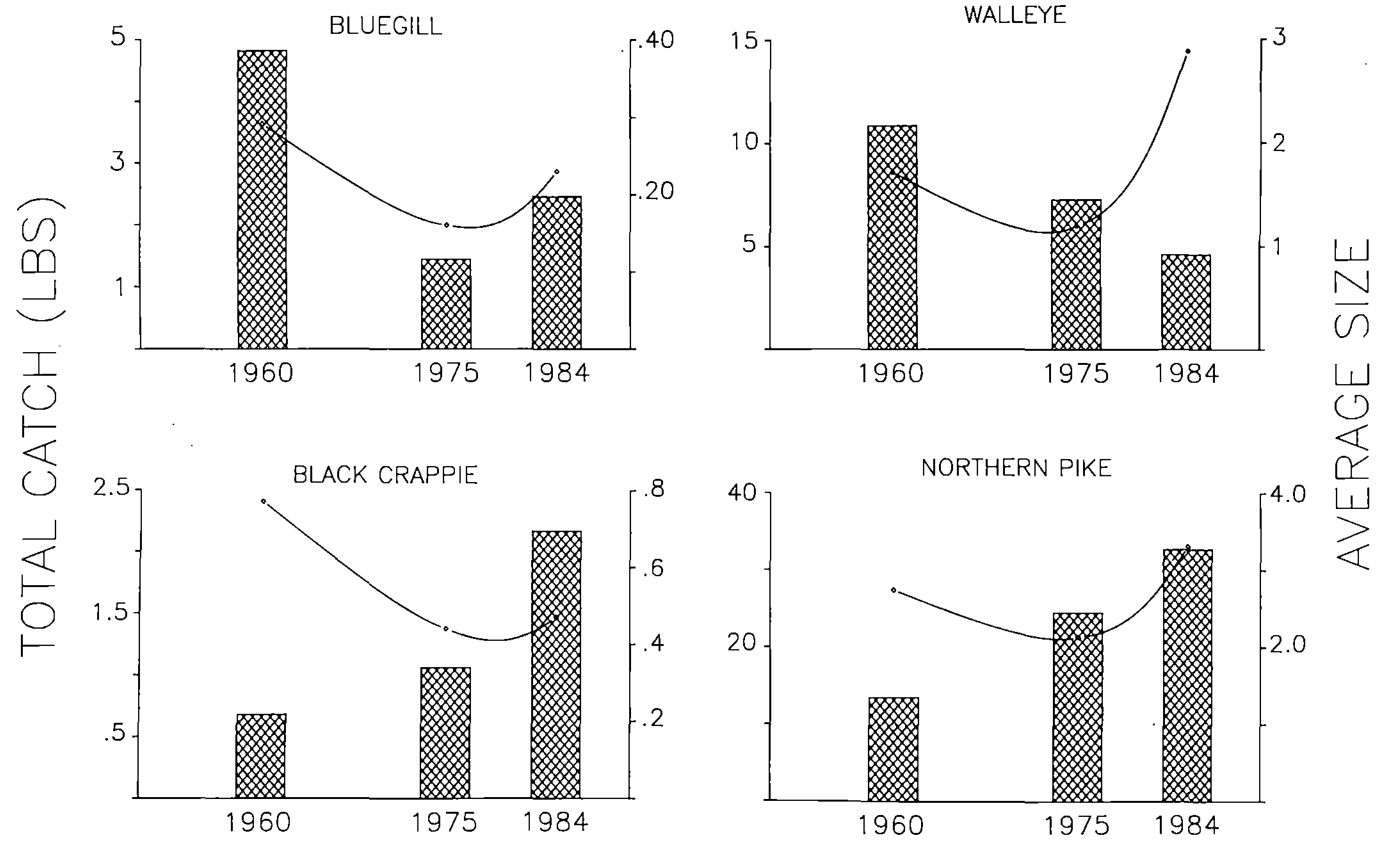

Figure 2. Total catch (bars) and average size of four popular game fish taken from Lake Itasca, Minnesota. The data for the three years shown (1960, 1975, and 1984) are summaries of DNR surveys. Total catch is a measure of fish biomass expressed in pounds; it was obtained by summing the average number of fish caught.

In the near future, Lake Itasca may undergo a shift in its equilibrium state. If we are in a warming trend (Table 1), there will be profound impacts on lake biotas, because temperature regulates metabolic rates of invertebrates and fish. In exceptionally warm years, zooplankton become very abundant because they have a "jump" on their predators (10). Perhaps a greater consequence of rising temperatures involves the behavior of young-of-the-year (0+ fish). The predominant yellow perch are early spawners. Upon hatching they have characteristic movement patterns during their early development (8). We have observed that these patterns are disrupted when lake temperatures are high during late May (Whiteside and Hatch, unpublished). Instead of their normal limnetic phase, the 0+ perch disperse throughout the lake. We are uncertain of the consequences of this behavior. There are potentially significant ramifications that pose several intriguing questions. Does it enhance survival for 0+ perch? What are the effects on later spawning sunfish (i.e., is there heavy predation by 0+ perch on newly hatched bluegills?)? These are important questions, in that their answers may hold the key to explaining future alterations in the fish community that could impact the ecosystem.

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