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PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF THE TURKEY LAKES WATERSHED, CENTRAL ONTARIO, CANADA

by

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Management Perspective

This paper acts as the introductory chapter for the collection of 20+ papers from the Turkey Lakes Watershed Study that are to be published in a special volume of the Canadian Journal of Fisheries and Aquatic Research. The paper contains fundamental physical, chemical, and biological information on the watershed and thereby acts to establish the field setting for all subsequent papers.

On its own, this paper bears no implications for departmental policies. However, the overall collection of papers will present results and interpretation of the first five calendar years of the Turkey Lakes Watershed Study including those from terrestrial investigations (Canadian Forestry Service), aquatic biological studies (Department of Fisheries and Oceans), as well as aquatic chemical research from the National Water Research Institute and the National Hydrology Research Institute. Hence, this special volume will provide an important, multidisciplinary data source that will be invaluable for future evaluation of the impacts of acidic deposition on Shield terrain. It will also facilitate the ongoing activity of integrating the results into a single, coherent picture.

Perspective-gestion

Le present document sert de chapitre d'introduction dans un recueil de plus de vingt études du bassin hydrographique des lacs Turkey qui doivent être publiées dans un volume spécial du Canadian Journal of Fisheries and Aquatic Research. Ce document contient les informations physiques, chimiques et biologiques de base sur le bassin hydrographique et constitue donc un point de référence pour les conditions sur le terrain de toutes les publications ultérieures.

Ce document n'a en soi aucune incidence sur les politiques ministérielles. Le recueil d'études présentera cependant les résultats et l'interprétation des cinq premières années civiles de l'étude du bassin hydrographique des lacs Turkey, y compris ceux des études terrestres (Service canadien des forêts), des études biologiques aquatiques (Pêches et Océans) et des recherches chimiques aquatiques effectuées par l'Institut national de recherche sur les eaux et de l'institut national de recherche hydrologique. Ce volume spécial constituera donc une important source de données multidisciplinaires très précieuses pour les évaluations futures des répercussions des dépôts acides sur les terrains due Bouclier canadian. Il facilitera également l'intégration permanente des résultats en un ensemble unique et cohérent.

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Abstract

As an introduction to the special volume on "acid rain" studies in the Turkey Lakes Watershed, Algoma, Ontario, this paper summarizes basin characteristics in order to establish the field setting in which the research was originally initiated and continues to this day. Basic information on climatology and basin geomorphology as well as general geology, and aquatic and terrestrial chemistry are presented. The latter includes a brief discussion of observed spatial variability and comparison with other calibrated watersheds. Aquatic biology includes descriptive information on fish, benthos, plankton, and primary production. The section on the terrestrial portion of the watershed includes information on dominant vegetation types, characterization of the basic forest dimensions, and a comparison of foliar element concentration with those observed in a similar forest at Hubbard Brook, New Hampshire.

Jeffries, D.S., J.R.M. Kelso, and I.K. Morrison. 198 . Physical, chemical, and biological characteristics of the Turkey Lakes Watershed, central Ontario, Canada. Can. Spec. Publ. Fish. Aquat. Sci.

Résumé

En guide d'introduction au volume spécial sur les études des "pluies acides" dans le bassin hydrolographique des lacs Turkey à Algoma en Ontario, le présent document résume les caractéristiques du bassin afin d'établir les conditions sur le terrain dans lesquelles les recherches ont commencé et se poursuivrent jusqu'à ce jour. On y présente des données de base sur la climatologie et la géomorphologie du bassin ainsi que sur la géologie générale et la chimie aquatique et terrestre. Cette dernière comprend un bref examen de la variabilité spatiale observée et une comparaison avec d'autres bassins hydrographiques étalonnés. La biologie aquatique comprend une description de poissons, du benthos, du plancton et de la production primaire. La section sur la partie terrestre du bassin hydrographique comprend des information sur les types dominants de végétation, la caractérisation des dimensions de base de la forêt et une comparaison de la concentration de l'élément foliare avec celles observées dans une forêt semblable à Hubbard Brook, New Hampshire.

Introduction

The Turkey Lakes Watershed Study (TLWS) was initiated in 1980 to define the impact of atmospheric deposition of acidifying substances and other pollutants on undeveloped aquatic and terrestrial terrain. In the intervening period, numerous field oriented studies have emphasized quantification of the basin's response to elevated deposition of strong acids; some work also has been directed towards metal and organic contaminants.

While several reports exist that describe specific attributes of the TLW, (e.g. Jeffries and Semkin, 1982; Semkin and Jeffries, 1983; Kusmirski and Cowell, 1983; Craig and Johnston, 1983; Wickware and Cowell, 1985), there is no systematic presentation of the characteristics of the basin that permits comparisons with other aquatic/terrestrial systems in general, or other sites intensively studied to define the effects of the long range transport of airborne pollutants (LRTAP) in particular. Our intention here is to provide this information, and to place it in a regional perspective and to compare it, when appropriate, to that from other calibrated watersheds. This will establish the setting for the results presented in the subsequent papers of this volume.

Study Site Selection

Criteria for selecting a "calibrated watershed" study site were based on the need to fill a vacant niche in the overall Canadian research program investigating the effects of LRTAP on Shield terrain. Given the existence of other calibrated systems in eastern Canada located on a variety of terrain types, we sought a site on the Canadian Shield having a reasonably undisturbed Great Lakes-St. Lawrence Forest type that was regionally representative of the aquatic and terrestrial resources of the area. Also, we wished to capitalize on the perceived moderate geochemical "sensitivity" to acid rain typified by the region, and to the perceived moderate level of atmospheric deposition (0.4 - 0.6 $keq.ha^{-1}.yr^{-1}$ wet SO_4^{2-}). From the information available prior to 1980, the TLW (Figure 1) was chosen in the Algoma district of Ontario to complete a range within the Canadian program at large in deposition, geological, biological, and chemical conditions. The TLW, chosen from some 100 potential candidates, is located approximately 50 km north of Sault Ste. Marie within the highlands east of Lake Superior; the basin subsequently has proven to meet the criteria except that it normally receives atmospheric deposition at the upper end of the above range (see Sirois and Vet, this volume).

In eastern Canada, the area south of latitude 52° is generally considered sensitive to elevated atmospheric deposition (Kelso _et al_. 1986); it contains approximately 720,000 lakes at risk. Most of these lakes (Table 1) are <10 ha, and the overwhelming majority, 96.8%, are <100 ha. The distribution of lake sizes in the Sault Ste. Marie district closely parallels the situation in eastern Canada as a whole, and the lakes in the TLW are among the type considered most at risk.

Compared with other calibrated basins in North America, the TLW possesses a unique characteristic; namely, the watershed contains a chain of four lakes (Figure 2) that exhibits a gradient in chemical composition within a single defined system. This feature of the basin has already been exploited to show (1) the relationships that exist between chemical composition and primary production (Lam et al., 1986), (2) the differences present in ion mass balances between a high and low elevation lake (Jeffries et al., 1986), (3) the spatial variation in surface water composition occurring in response to short-term acidification from spring snowmelt (Jeffries and Semkin, 1983), and the change in fish standing stock and production in a cascading lake system (Kelso, 1985).

Physical and Geochemical Characteristics

Compared to the other calibrated watersheds, the TLW is undisturbed, has high relief, and climatically, is a fairly wet environment. Logging records for the area show that it has been undisturbed for approximately 30 yr (a very small, selective harvest occurred in the mid 1950's); also, there have been no significant natural disasters (forest fires, etc.). Apart from one hunter's cabin inhabited perhaps two weeks each year, the basin is unoccupied. The closest point-source emitter of air pollutant is the steel industry located at Sault Ste. Marie.

Elevation at the lowermost stream gauging station is 340 m AMSL while the highest point is atop Batchawana Mountain (630 m) on the northern edge of the basin - giving an overall relief of 290 m. The large variations in elevation and the leeward position relative to Lake Superior influence the quantity of precipitation received. Semkin and Jeffries (1986) recorded an average annual precipitation of 1212 mm from 1981 - 1984 at low elevations and up to 15% more at higher levels. In comparison, Sault Ste. Marie, which lies south of the highlands containing the TLW, receives only 935 $mm.yr^{-1}$ (long-term average).

The watershed is almost entirely underlain by Precambrian silicate greenstone (i.e. metamorphosed basalt) with only small outcrops of more felsic igneous rock occurring north of Batchawana Lake and near the main inflow to Little Turkey Lake (Semkin and Jeffries, 1983). Regional fault systems tending in approximately NW-SE and SW-NE directions have exerted some control over water drainage giving the rather angular drainage pattern observed in Figure 2. A two-component glacial till overlies the bedrock. Till thickness varies from <1 m at high elevation locations (with frequent surface exposure of bedrock) to 1 - 2 m at lower elevation, and with the occasional occurrence of extremely deep till sequences (up to 70 m) when valleys in the bedrock have been entirely filled (Elliot, 1985). The mineralogy of the till is more felsic than the underlaying bedrock showing that the material was likely primarily derived from the large granitic intrusions that occur just north of the basin

(Kusmirski and Cowell, 1983). Finally, the tills contain a small but measureable amount of $CaCO_3$ (0 - 2%) that increases with depth, and is higher (on average) at lower elevation locations (Craig and Johnston, 1983). The most frequently encountered soil types on upland sites within the basin are Ferro-Humic and Humo-Ferric Podzols (Canada Soil Survey Committee, 1978).

The headwater lake in the TLW is Batchawana Lake which is separated into two distinct basins (North and South). The outflow stream draining Batchawana Lake South (and subsequent portions of the watershed) is called Norberg Creek and traverses a rapid change in elevation (497 to 388 m) prior to entering Wishart Lake - the shallowest lake in the basin. Little Turkey Lake and, finally, Turkey Lake follow Wishart Lake. The outflow from the TLW enters the Batchawana River below the perimeter of the basin, and thence passes on to Lake Superior. The physical characteristics and water renewal rates for all the lakes are summarized in Table 2 and their morphometries are shown in Figure 3. The relatively high precipitation occurring in the TLW causes the lakes to flush fairly rapidly.

The thermal structure of the lakes in the TLW is controlled by solar radiation and wind speed. As with most lakes located in cool, temperate climates, the lakes exhibit two periods of thermal stratification - inverse stratification under the ice cover from December to April, and direct stratification in the warm summer/fall months (mid-May to the end of October). The stability of the thermal stratification breaks down in the autumn and spring when complete mixing of the water column can be achieved. Therefore, lakes in the TLW may be considered dimictic; however, in reality the occurrence of spring "turnover" is often incomplete due to an extremely rapid increase in surface water temperature and ineffectual wind-induced mixing. Mixing during fall turnover is generally complete. It should be noted that Wishart Lake must necessarily be an exception to the above thermal classification since it is relatively shallow and is often fully mixed by winds during the summer months.

Aquatic Chemistry

Dissolved Oxygen

The sediments and undisturbed bottom waters of the lakes all exert a D.O. demand. Batchawana Lake, Little Turkey Lake and Turkey Lake exhibit two periods of D.O. stratification, i.e. during the ice-covered period (December to April), and during the summer months. Wishart Lake is continuously stratified only in winter since wind-induced mixing of this shallow lake occurs occasionally during the summer months. Even during the summer, however, there are transient periods of O_2 depletion in the bottom waters of Wishart Lake between strong wind events.

The bottom waters in the north and south basins of Batchawana Lakeand Little Turkey Lake become anoxic during both stratification periods. Because of increased microbial activity, the hypolimnetic O_2

demand is greatest in the summer and early fall with maximum O_2 depletion occurring in late September. Microbial decomposition processes are most likely occurring in the hypolimnion and sediments of Turkey Lake as well; however, the O_2 pool present in the relatively large hypolimnion of this lake is sufficient to preclude development of anoxic conditions. The small northwestern basin of Turkey Lakes does deselop anoxic bottom waters. Finally, the development of reduced O_2 under the ice in Wishart Lake shows that its sediments are also exerting an O_2 demand.

Major Ion, Nutrient, and Metal Chemistry

A summary of the median concentration for ionic, nutrient, and metal parameters for whole lake volume-weighted samples is given in Table 3. Note that all data in Table 3 are expressed as $\mu mol.L^{-1}$. the most important cation in surface waters of the TLW is Ca^{2+} as would be expected from simple weathering of a silicate terrain (Holland, 1978); however, the strength of the dominance of Ca^{2+} over all the other cations probably reflects the presence of the very easily weathered $CaCO_3$ in the tills. While the order of dominance for cations (on an equivalents basis) is the same for all the lakes (Ca^{2+} > Mg^{2+} > Na^+ > K^+), the two most important anions change position part way down the chain. Above and including Wishart Lake, the equivalent anion order of dominance is SO_4^{2-} > HCO_3^- >> NO_3^- = Cl^-, while the order for Little Turkey Lake and Turkey Lake is HCO_3^- > SO_4^{2-} >> NO_3^- >

Cl^-. Note that NO_3^- and Cl^- both have very low concentrations compared to HCO_3^- or SO_4^{2-}. Note that for the discussion here, HCO_3^- = Alkalinity = Alk. Surface waters in terrain having silicate bedrock with no widespread occurrence of sulphide mineralization and receiving low levels of acidic deposition generaly have HCO_3^- as the dominant anion (Livingstone, 1963; Jeffries _et_ _al_., 1986). The atmospheric input of SO_4^{2-} tends to alter the anion chemistry of these waters. In situations where physical and/or geochemical conditions limit the interaction of incoming precipitation with soils and bedrock, then the runoff waters are very dilute and often have SO_4^{2-} as the dominant anion. Such is the case in the TLW where the steep slopes and, particularly, the paucity of till in the upper reaches of the basin restrict geochemical interaction. Hence, there is a strong gradient in the concentration of both Alk and Ca^{2+} (i.e. both increasing downsteam) while the other ions exhibit comparatively minor spatial variability within the basin. The occurrence of a positive downstream gradient in Alk to the extent that the "abnormal" SO_4^{2-} dominated system is replaced by the "normal" Alk dominated system has been observed in other locations affected by acidic deposition (e.g. Hubbard Brook, Johnson _et_ _al_., 1981).

Groundwater composition in the basin exhibits wide variation on a site specific basis. One major reaction controls the groundwater chemistry, i.e. SO_4^{2-} dominated recharge waters evolve to Alk dominated groundwater through weathering of $CaCO_3$ in the overburden. Different groundwater ion concentrations at different sites are caused by differing water flow paths (therefore yielding differing water-till contact times) and differing $CaCO_3$ availability. These factors combine to give a pattern of generally low groundwater Alk at higher elevations in the watershed, and higher Alk groundwaters at low elevations.

Table 4 presents data to compare the range of pH and concentration of the most important ions observed in the TLW to those reported for other Shield locations. The range in pH observed in the TLW is similar to that found in other locations in Ontario and Quebec, except for Sudbury where numerous low pH lakes occur. Low pH lakes such as observed in Nova Scotia (Kejimkujik) and the Adirondack Mountains of New York State (ILWAS) are not present in the TLW.

Calcium and Alk concentration, particularly in the lower portions of the basin, are at the high end of the range of data presented in Table 4. This agrees with the regional variation observed by Jeffries et al. (1986) and primarily reflects the presence of $CaCO_3$ in the glacial till. Locations which are geographically separated from a $CaCO_3$ source area have much lower Ca^{2+} concentrations (ELA, Lac Laflame, and Kejimkujik), while Alk concentrations vary depending on the intensity of acidic deposition. Sudbury area lakes that have experienced very high deposition in the past due to local sources are the end-member of this compilation having both very high Ca^{2+} levels and negative Alks.

Sulphate concentrations vary among the different locations in Table 4 in a pattern similar to deposition. Hence, low deposition areas (ELA $<$ Kejimkujik) have low lake SO_4^{2-} concentrations, while high deposition areas (Sudbury, Muskoka-Haliburton, and ILWAS) have the highest values. The TLW and Lac Laflamme both exhibit intermediate values that may be slightly higher than a nearby regional mean, since they both occupy highland positions and therefore receive slightly higher precipitation quantities (and deposition) than the surrounding areas.

Median Total P concentrations observed for volume-weighted samples were 0.16-0.19 $\mu mol.L^{-1}$ across all the lakes. Median Total N concentrations (TKN + NO_3^-) vary from 29-39 $\mu mol.L^{-1}$. Phosphorus is clearly the limiting nutrient in these waters (Schindler, 1977).

Nitrate concentrations in the TLW are very much higher than those from neutral lakes in the Sudbury area studied by Yan and Miller (1984). Yan and Miller also observed higher NO_3^- concentrations in acidic lakes and attributed this fact to reduced asimilatory or dissimilatory NO_3^- reduction rather than elevated watershed inputs. We believe that the reverse situation is occurring in the TLW. The terrestrial basin is retaining a much smaller fraction of the NO_3^- deposited to the basin than occurs at Sudbury. Retention coefficients in the TLW are in the range 0.2-0.7 compared to 0.9-1.0 at Sudbury (see Jeffries et al., 1984). The implications of NO_3^- "leakiness" in the TLW with respect to basin acidification is discussed by Jeffries et al. (this volume). Ammonium-N concentrations are very much lower than NO_3-N in both terrestrial runoff and the lakes. Nutritional requirements for N appear to be principally satisfied by NH_4^+ in the TLW. Finally, among all the lakes, Wishart Lake consistently shows the highest concentrations for all N parameters.

Total Al, Fe, Mn, and Zn were the only trace metals that consistently showed concentrations above analytical detection limits and were therefore included in Table 3. Concentrations of total Cu, Ni, and Pb were almost always less than detection (0.010 $mg.L^{-1}$). Metal concentrations are generally similar to those observed in neutral lakes at Sudbury and Muskoka-Haliburton (see Table 7.5 in Yan and Miller, 1984). Copper and Ni values are much lower than those observed near Sudbury.

Within the basin, downstream lakes tend to have the lowest trace metal concentrations which probably reflects their higher pH values. However, Batchawana Lake South has the highest median values for three of four trace metals despite the fact that Batchawana Lake North has a slightly lower median pH and Alk concentration. The southern sub-basin of Batchawana Lake has a greater number of defined headwater streams draining into it, some with relatively low pH. Of four such streams, annual volume-weighted pH values for the 1981/82 water year were 5.12, 5.54, 5.94, and 5.17 (GLFC streams F47-F50, respectively, see Jeffries _et al_., this volume). This may be the explanation for the maximum median metal values observed in Batchawana Lake South.

Seasonal variation in the lake and outflow chemistry in the TLW can be large (two-fold and much greater for some parameters). The magnitude of the variation is usually controlled by spring snowmelt. Semkin _et al_. (1984) showed that the hydrological flux through the basin was the main factor controlling the chemical composition for both lake outflows and Norberg Creek. For the years, 1980-1983, the

April + May discharge at Turkey Lake outflow (station S4) accounted for approximately 40% of the total annual flow. Similarly, Nicolson (1984) calculated that the 1981 spring runoff produced 38-55% of the total annual discharge for several headwater streams in the basin. Maximum annual H^+ and NO_3^-, and minimum base cation and Alk concentrations in stream and lake surface waters usually occur during the spring melt episode (Jeffries and Semkin, 1983; Semkin and Jeffries, 1986). Also, the increased flux of acidity associated with the snowmelt waters can cause the mobilization of metals such as Al from the soils into the aquatic regime, especially in headwater areas of the basin where the overburden is relatively thin and the $CaCO_3$ content low (Jeffries, unpub. data). In contrast, the SO_4^{2-} content of surface waters remains relatively uniform throughout spring melt; spring (March 1 to May 31) SO_4 concentrations in Norberg Creek are only 2% higher than levels recorded during the remainder of the year (Semkin et al., 1984).

While variations in lake and stream chemistry are most dramatic during spring melt, their composition also responds to atmospheric deposition associated with high precipitation events or periods. Sulphate and H^+ are the predominant ions in bulk deposition in the TLW on an annual basis (Semkin and Jeffries, 1986; Sirois and Vet, this volume). Heavy rain such as occurred in the autumns of 1982 and 1983 generated pH depressions that are coincident with elevated SO_4 levels.

During summer, "base flow" conditions are often approached in Norberg Creek. With a significant input of groundwater and maximum biological activity in both the terrestrial and aquatic regimes, summer concentrations are typified by high pH, Ca^{2+}, and Alk values, and minimum NO_3^- and NH_4^+. The importance of biological activity controlling the concentration of N parameters is shown by the fact that mid-winter base-flow has much higher NO_3^- and NH_4^+ concentrations.

Aquatic Biology

Fish

Since lakes on the Canadian Shield generally tend toward oligotrophy, aquatic production systems tend toward salmonid dominated fish communities. Johnson et al. (1979) have shown that northern and central Ontario lakes are comprised largely of lake trout (Salvelinus namaycush) or lake trout related communities. Minns (1981) and Scott and Crossman (1973) have also shown that brook trout (Salvelinus fontinanlis) are also endemic and ubiquitous. The Sault Ste. Marie district (Table 5) is no exception to these generalities as most lakes, 86.6%, are comprised of lake trout, and brook trout alone or in combination with whitefish (Coregonis clupeaformis) and smallmouth bass (Micropterus dolomieu). Although the Canadian Shield supports most of the freshwater salmonid resource of Canada (Scott and Crossman, 1973; Martin and Olver, 1976), biomass and production tend to be less in these oligotrophic systems (Kelso, 1985; Hanson and Leggett, 1982).

In the Turkey Lakes watershed, no fish were caught in either basin of Batchawana Lake (Kelso, 1985). Fewer species, 8, occur in Wishart Lake than in either Little Turkey, 11 or Turkey Lake, 9. Seven species are common to all lakes in the watershed including brook trout, white sucker (*Castastomus commersoni*), burbot (*Lota lota*), lake chub (*Couesius plumbeus*), northern redbelly dace (*Chrosomus eos*) and emerald shiner (*Notropis atherinoides*) (Kelso, this volume).

The streams interconnecting the lakes and below the outlet of Turkey Lake support only a limited number of species and brook trout exist only in the stream below Turkey Lake. No fish were found at a stream monitoring station in Norberg Creek, consistent with the lack of fish in Batchawana Lake. Two species, lake chub and northern redbelly dace, were ubiquitous. Without exception, stream fish species were also found in lakes suggesting probable intermixing of stream and lake species.

Benthos

Lake sediments in the watershed are composed of soft, dark, refractory material with high water (91 to 95%) and organic content (29-45%) (Dermott, 1985). Both the water and organic content of the lake sediments increased progressively upward in the watershed. A significant negative correlation between lake pH and organic content existed for lakes in the Algoma Region. This relationship likely occurs since either the lakes of lower pH would undergo breakdown of organic material at a slower rate or because of a greater terrestrial contribution to these low pH systems.

In lakes, community segregation in the benthos was largely a function of site depth. Hierarchical clustering speareated the benthos into communities dominated by *Chironomus* sp. or *Chaoborus* sp. Other benthos groupings were dominated by a variety of chironomids or by the Tanytarsini. Most littoral sites (<5 m) were dominated by amphipods or equally by *Hyallela* and the Tanytarsini. All lakes contained sphaerid clams with large populations of *Pisidium casertanum* and *P. ventricosum* present in the littoral zones of Batchawana and Wishart Lake. Gastropods were scarce. Annilids were not abundant but tubificids, lumbriculids and Hirudinea were present in all the lakes. The mayflies (*Hexagenia limbata* and *Leptophlebia nebulosa* were common except in Batchawana Lake. Probably in response to presence of fish species, the *Chaoborus* species displayed a shift from *C. americanus* and *C. brunskilli* in Batchawana Lake to *C. flavicans* and/or *C. punctipennis* in the downstream lakes.

In general, in spite of differences in lake pH, the top 2 cm of sediment has a much narrower pH range, 5.8-6.2. Thus, it is not surprising to find nominal differences in the benthos with widely ranging lake pH. The major differences seen in the benthos among the lakes in the watershed are thus more likely a result of lake morphometry and the presence or absence of a fishery rather than acidification state.

Zooplankton

The species composition of the macrozooplankton in lakes of the Turkey Lakes Watershed is very similar (Table 6).

Diaptomus minutus is the dominant calanoid in all lakes. On occasion, two other dioptomids were also found: *D. leptopus* and *D. sicilis*. *Epischura lacustris* is also present in reduced numbers in each lake while the glacial relict, *Senecella calanoides* is found only in the deeper lakes.

Tropocyclops prasinus mexicanus is the dominant cyclopoid in all the lakes. *Cyclops scutifer* is also found in all lakes, but is far more abundant in Little Turkey and Turkey Lakes. *Mesocyclops edax* is also ubiquitous while *Orthocyclops modestus* has been found in small numbers in three of the five basins but is probably present in low numbers in all of them. *Cyclops biscupidatus thomasi* is also present in all lakes, but tends to be more abundant in the deeper lakes of the watershed.

The dominant cladoceran in all lakes is *Bosmina longirostris*. Both *Diaphanosoma brachyurum* and *Holopedium gibberum* also show seasonal dominances and are found in small numbers. *Daphnia pulex* is more abundant in the shallow Wishart Lake than the three deeper lakes, while the reverse is true for both *Daphnia dubia* and *Daphnia galeata mendotae*. *Daphnia retrocurva*, *Daphnia catawba*, and *Eubosmina coregoni* are rarely found.

Phytoplankton and Primary Production

Cyanophytes were the dominant algal species in all lakes. *Merismopedia punctata* was the major blue-green in both basins of Batchawana Lake and became almost the sole species during the summer peak period of production. Batchawana Lake did not undergo the extremes in change in species and production that occurred in the downstream lakes. In Wishart Lake *M. punctata* was significant but was coincident with an increase in abundance of *Microcystis flos-aquae* in early August. In Little Turkey Lake *Chroococcus dispersus* was always a major contributor to production, but production peaks were coincident with increased numbers of *Aphanothece clathrata* in July, *M. flos-aquae* in August and mid-September, and *Ceolosphaeriam minutissiumum* in late September. Most of these species were abundant in Turkey Lake with *C.dispersus* and *A. clathrata* being major contributors to the summer peaks in production.

When production is low during the colder months, few organisms, <1000 cells ml^{-1}, are present. The community is then composed of Chrysophyceae, Bacillariophyceae, Chlorophyta, Pyrrophyta and Cyanophyta.

Carbon assimilation by the phytoplankton varies with depth in each lake with maximum production consistently occurring between 1 and 4 m. For comparison among the lakes, only the maximum production (P_{max}) from *in situ* ^{14}C incubations was used regardless of the depth at which it occurred. Carbon assimilation was extremely limited,

<0.5 mg m^{-3} h^{-1}, both under ice cover and in early spring (Collins et al., 1983). Production increases in May and sharp production peaks are apparent during summer. Greatest assimilation rates were in Wishart Lake and peaks in production were always greater there. Conversely, production was usually lower in Turkey Lake.

Forest Conditions

Turkey Lakes Watershed is located within the Algoma (L.10) Section of the Great Lakes-St. Lawrence Forest Region (Rowe, 1972). The vegetation is characteristic of the section in general, with the greater part of the watershed itself dominated by an uneven-aged, though generally mature-to-overmature, old-growth tolerant hardwood forest. Main-stand ages throughout the watershed are typically 120 years and older. The principal tree species of the watershed is sugar maple (Acer saccharum Marsh.). Other tree species include eastern white pine (Pinus strobus L.), tamarack (Larix laricina (Du Roi) K. Koch), white spruce (Picea glauca (Moench) Voss), balsam fir (Abies balsamea (L.) Mill.), eastern white cedar (Thuja occidentalis L.), trembling aspen (Populus tremuloides Michx.), ironwood (Ostrya virginina (Mill.) K. Koch), yellow birch (Betula alleghaniensis Britton), white birch (B. papyrifera Marsh.), red oak (Quercus rubra L.), white elm (Ulmus americana L.), showy mountain-ash (Sorbus decora (Sarg.) Schneid.), serviceberry (Amelanchier sp. Med.), pin cherry (Prunus pensylvanica L.f.), red maple (A. rubrum L.), mountain maple

(*A. spicatum* Lam.), white ash (*Fraxinus americana* L.) and black ash (*F. nigra* Marsh.). Typically, on upland, the maples account for 90%, other hardwoods 9%, and conifers 1% of the total phytomass. On some lowland sites, the proportion of conifers is higher.

Sitewise, Turkey Lakes Watershed is located within the Batchawana Site District of Site Region 4E (Lake Timagami) (Hills, 1955). A forest ecosystem classification of the watershed was developed from a detailed survey and sampling of vegetation and soils (Wickware and Cowell, 1985). The classification recognized 17 unique forest vegetation associations plus open wetland, and 9 soil classifications. The most frequently occurring vegetation association was *Acer saccharum*/*Smilacina racemosa* and this was subsequently divided into 4 variants based on the occurrence of specific herbs, shrubs, etc. In general, Wickware and Cowell (1985) found vegetation and soil types not to be deterministically associated, although some trends were evident. For mapping purposes, 9 Map Unit Types, representing similar and repetitive patterns of soil and vegetation landscape, mapable at a scale of 1:12000, were recognized.

To obtain data on forest productivity, a systemmatic, 1.0% forest survey of the watershed was conducted in 1982. This involved establishing 216 0.05 ha temporary sample plots, and characterizing these according to forest vegetation type. Mean forest dimensions for the principal types encountered in the basin are given in Table 7. The most-frequently-encountered association, the *Acer*/*Smilacina* Vegetation Type, accounted for over half of the area sampled. While substantial variation did occur within types, on average, stocking, mean dominant height, mean diameter-at-breast-height (DBH), basal area (BA), gross total volume, and gross merchantable volume were similar across types. Total standing phytomass was somewhat more variable due to differing proportions of hardwood and softwood species. Characteristic of the northerly latitude (47°3'N), mean dominant heights were generally short, ca 20 m, with 94% of the plots being classified as Site Class II or lower (Plonski, 1974). Mean BA, gross total volume, gross merchantable volume and standing phytomass over all forest types on the watershed as a whole was 25.2 $m^2.ha^{-1}$, 205.9 $m^3.ha^{-1}$, 196.2 $m^3.ha^{-1}$ and 201.5 $tonnes.ha^{-1}$, respectively. Maximum BA encountered was 40.7 m^2 ha^{-1} for a plot on Acer/Smilacina type; maximum gross total volume, 406.0 m^3 ha^{-1} for a plot on the Acer/Taxus type; and maximum phytomass, 345.0 tonnes ha^{-1} for a plot on the Acer/Rubus type.

Healthwise, there have been no untoward insect and/or disease problems reported on the watershed or in the general area during recent years though, on average, stand quality across the watershed is low. In a survey of potential crop trees on a subset of 15 permanent sample plots across a range of vegetation types, 1% of stems were assigned to the first, 21% to the second, 68% to the third and 10% to the fourth of four quality classes, ranging from best to poorest. Nevertheless, Algoma District, wherein is situated Turkey Lakes Watershed, supports viable lumber and veneer industries, with the principal commercial species being yellow birch, sugar maple and eastern white pine. Man-made disturbance to the Turkey Lakes forest has been minimal, the one exception being a mid-1950s logging operation in which was removed, on average, an estimated 4 $m^3.ha^{-1}$ (ca 3% of total standing volume of the day) of veneer and/or sawlog quality yellow birch and white pine.

A partial characterization, at least, of the bioelement status of forests can be effected by analysis of foliage. In general, for comparably-sampled-and-analyzed foliar materials, concentrations of elements found in the trees of the Turkey Lakes Watershed followed the trend of values reported in the literature for sugar maple and yellow birch. Table 8 compares concentrations of elements in late-summer mid-crown foliage of ca 100-year-old sugar maple and yellow birch trees on an acid till soil at Turkey Lakes Watershed (Morrison, 1985) and in ca 70-year-old trees of the same two species from a maple-birch-beech woods on an gneis and quartz monzonite-derived acid till at Hubbard Brook, New Hampshire (Likens and Bormann, 1970). Concentrations of most elements were similar at both locations, the two groups differing mainly in relation to P, Fe and Mn levels, which were appreciably lower at Turkey Lakes Watershed. Also on a well-drained acid till in New Hampshire, Holye (1965) reported foliage of yellow birch trees to contain by weight 2.47% N, 0.19% P, 1.02% K, 0.97% Ca, 0.27% Mg and 0.17% S. In contrast, in mature sugar maple trees on a dolomitic limestone-derived till in southern Ontario, Ellis (1975) reported a late August elemental composition substantially different than that of the Turkey Lakes trees. Concentrations of Ca and Na were appreciably higher, while concentrations of N, K, Mg and Zn were appreciably lower than those of the present study. Concentrations of P were similar.

Several features commend the forest of the Turkey Lakes Watershed for the baseline and research studies being undertaken there. First, the forest is an accessible, but little-disturbed example of a natural vegetation rapidly disappearing from eastern North America. The area, in general, is well-removed for local sources of pollution and receives mainly long-range transported pollutants. It is a climax forest of advanced age, stable but stessed by the rigours of the northerly climate. This, some argue, opens it to stress. The objective of the forest studies associated with the Turkey Lakes Watershed Study is to determine if, in fact, stress imposed by regional air pollutants, acting on and through biogeochemical properties and processes, are sufficient to effect a measureable loss in productivity or produce a significant deleterious effect on the health of the important tolerant hardwood forest type represented by the forest of the Turkey Lakes Watershed.

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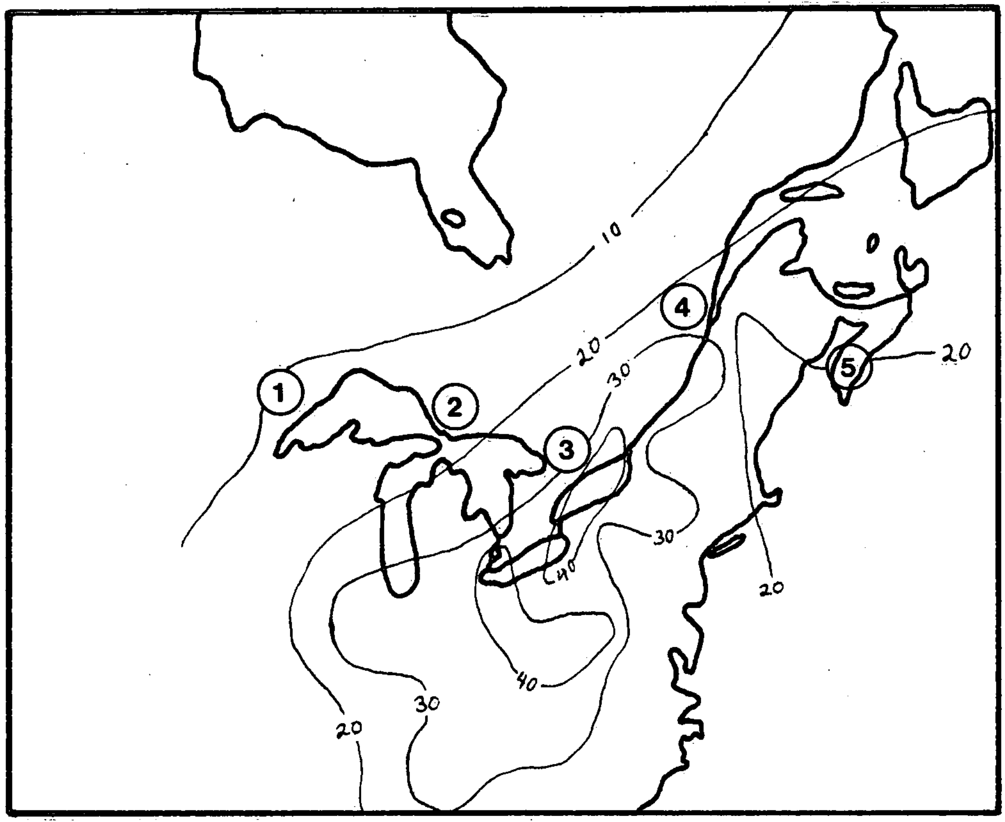


Fig 1.

Fig 2

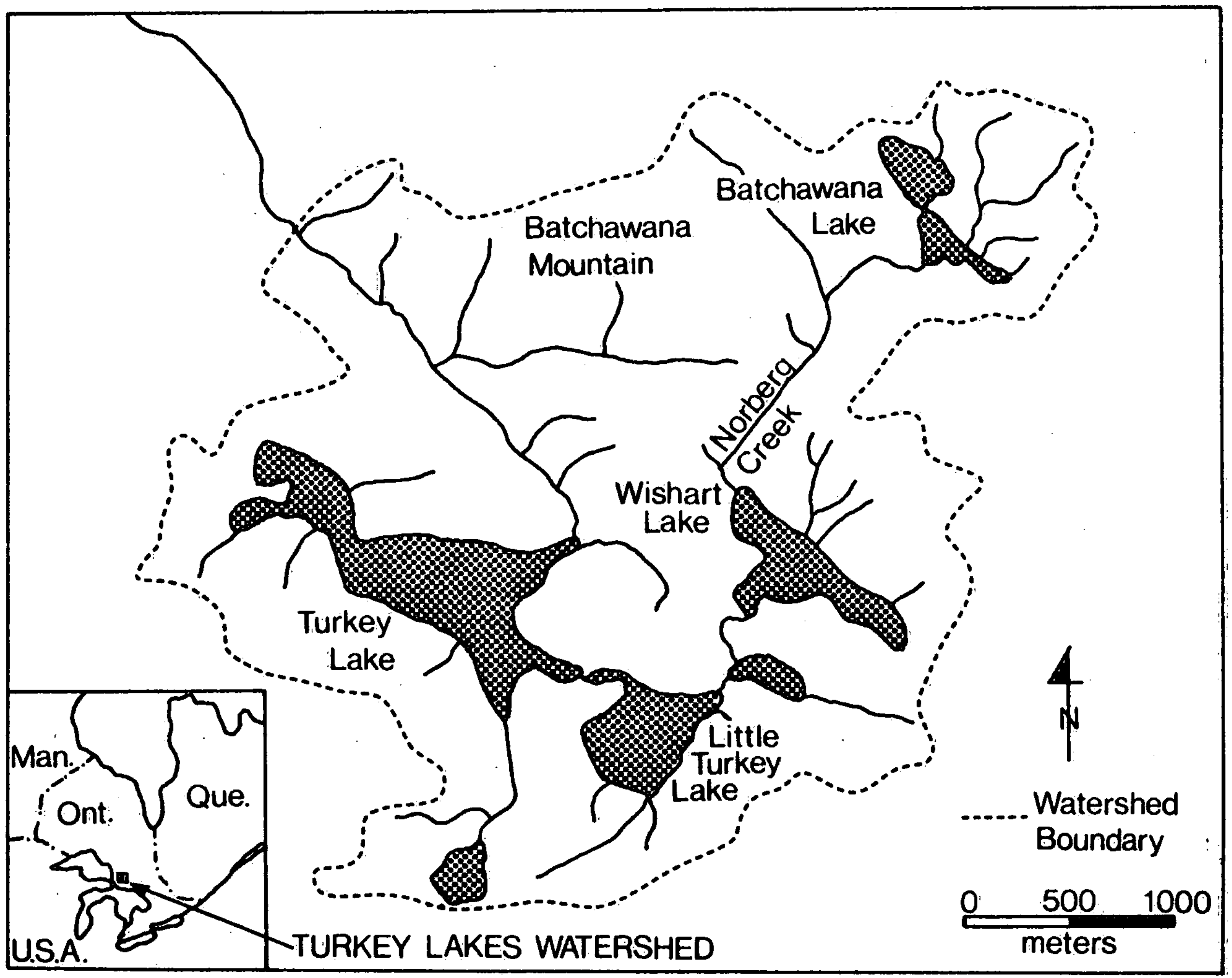
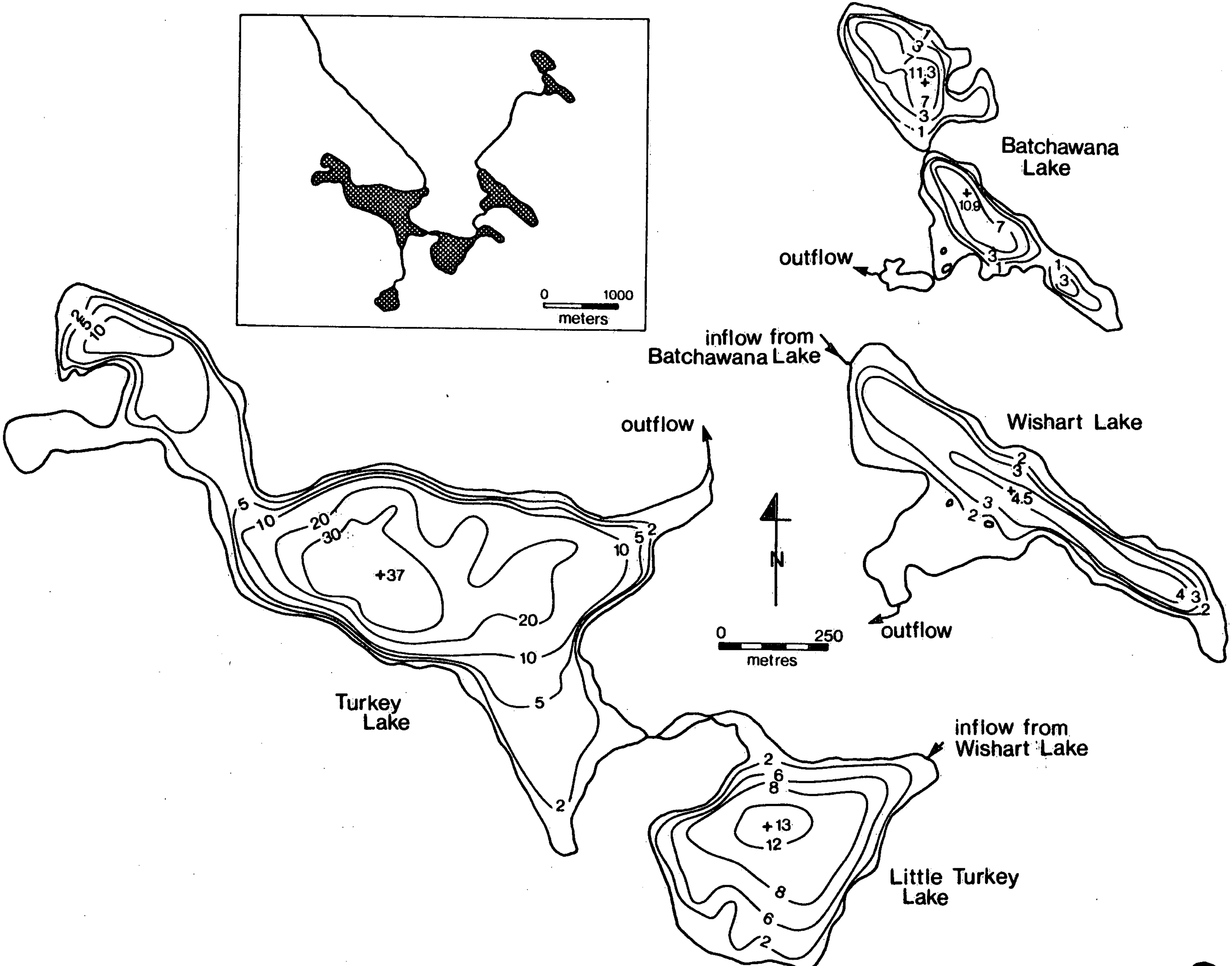

Batchawana Lake
Batchawana Mountain
Norberg Creek
Wishart Lake
Turkey Lake
Little Turkey Lake
N
Watershed Boundary
0 500 1000
meters
Man.
Ont.
Que.
U.S.A.
TURKEY LAKES WATERSHED

Fig 3



Batchawana
Lake
11.3
10.9
outflow
inflow from
Batchawana Lake
Wishart Lake
4.5
outflow
0
250
metres
N
Turkey
Lake
+37
outflow
inflow from
Wishart Lake
Little Turkey
Lake
+13
0
1000
meters

Table 1. Distribution of lake size in the Sault Ste. Marie district, Ontario (from Cox 1978), and eastern Canada south of latitude 52° north (Kelso et al. 1986)

Lake Size (ha)	Sault Ste. Marie District (%)	Ontario (%)	Eastern Canada (%)
<1	19.5	-	-
1-9	63.6	57.5	72.2
10-99	16.0	36.0	24.6
100-999	1.2	5.8	2.9
>1000	<0.1	<0.1	<0.1
Total No. Lakes	4,913	126,278	716,922

Table 2. Physical characteristics and water renewal times for lakes in the Turkey Lakes Watershed

Lake	Drainage Basin Area (ha)	Lake Surface Area (ha)	Maximum Depth (m)	Mean Depth (m)	Lake Volume ($m^3 \cdot 10^5$)	Water Renewal Time (yr)
Batchawana North	24.0	5.88	11.3	3.87	2.27	1.3
Batchawana South	85.6	5.82	10.9	3.27	1.90	0.30
Wishart	337	19.2	4.5	2.19	4.21	0.15
Little Turkey	491	19.2	13.0	6.04	11.6	0.25
Turkey	803	52.0	37.0	12.2	63.4	0.94

Table 3. Median pH, ion, nutrient*, and total metal concentrations ($\mu mol.L^{-1}$) for volume-weighted samples collected from the 4 lakes in the Turkey Lakes Watershed. Samples were collected from 1980 to 1985. Number of samples varies from 29 to 107 depending on lake and parameter. The range in mean groundwater ion concentrations observed for 34 piezometers within the basin are also presented.

Parameter	Batchawana Lake		Wishart Lake	L. Turkey Lake	Turkey Lake	Groundwater
	North	South				
pH	6.0	6.1	6.7	6.6	6.7	5.0-8.0
Ca^{2+}	55.4	66.9	99.3	119	138	47-775
Mg^{2+}	17.3	18.9	20.6	22.0	21.0	15-250
Na^{+}	21.3	20.1	25.2	27.1	26.2	24-237
K^{+}	7.2	6.6	6.9	7.4	7.8	4-36
Alk	39.8	53.2	114	142	180	15-2150
SO_4^{2-}	53.4	57.3	60.6	62.7	62.5	33-111
Cl^{-}	9.2	11.1	10.3	10.4	9.6	6-48
Total P	0.18	0.18	0.16	0.16	0.15	-
NH_4^{+}-N	3.57	3.28	2.64	2.43	1.00	-
NO_3^{-}-N	7.9	10.7	16.4	15.0	14.3	-
TKN	20.7	20.0	22.8	17.1	15.7	-
SiO_2	28.0	43.4	52.6	52.8	41.4	-
DIC*	55.8	86.6	83.3	79.1	69.1	-
DOC*	341	391	380	393	380	-
Al	3.22	4.89	2.81	2.39	1.22	-
Fe	1.31	1.71	1.00	0.71	0.34	-
Mn	0.58	0.47	0.46	0.40	0.13	-
Zn	0.11	0.13	0.06	0.05	0.04	-

*DIC and DOC values are approximate only.

Table 4. Comparison of pH and the concentration of Ca^{2+}, Alk, and SO_4^{2-} ($\mu eq.L^{-1}$) for the Turkey Lakes Watershed, Experimental Lakes Area (northwest Ontario), Muskoka-Haliburton (south central Ontario), Sudbury, Lac Laflamme (southern Quebec), Kejimkujik (Nova Scotia), and ILWAS (Adirondacks of New York State).

Location	pH	Ca	Alk	SO_4
Turkey Lakes Watershed[1]	6.0 - 6.7	111 - 276	40 - 180	107 - 125
EKA[2]	5.8 - 6.7	80	62	63
Muskoka-Haliburton[3]	5.8 - 7.0	150	110	170
Sudbury[4]	-	280	<0	530
Lac Laflame[5]	6.1 - 6.3	120 , 130	92 , 134	96 , 77
Kejimkujik[6]	5.0	38	<0	81
ILWAS[7]	4.7 - 6.2	73 - 207	-10 - 147	123 - 163

[1]Range of medians in TLW represented by Batchawana L. North and Turkey L., respectively, 1980-1985.

[2]Armstrong and Schindler (1971); mean ion concentrations for 40 lakes, 1968-1969.

[3]Harvey et al. (1981); mean ion concentrations for 14 lakes, 1976-1979.

[4]Dillon et al. (1980); mean ion concentrations for acidic lakes in the Sudbury area (pH probably <5.5).

[5]Papineau (1983); mean pH and ion concentrations for 1981 and 1982.

[6]Kerekes et al. (1982); mean pH and ion concentrations for 1979-1980; note that Kejimkujik has a maritime climate and its ion chemistry is strongly influenced by sea-salt inputs.

[7]Schofield (1984); minimum and maximum annual average concentrations among Woods, Sagamore, and Panther Lakes, 1978-1980.

Table 5. Fish community composition (game fishes only) of lakes in Sault Ste. Marie district. Data are summarized from lake survey files of the Ontario Ministry of Natural Resources, district office, Sault Ste. Marie.

Fish Type	No. of Lakes	%
Brook trout only	82	45.8
Brook - lake trout	43	24.0
Lake trout only	15	8.4
Lake trout - smallmouth bass	9	5.0
Brook trout - whitefish	3	1.7
Brook trout - lake trout - whitefish	3	1.7
Walleye	3	1.7
Northern pike	6	3.4
N. pike - smallmouth bass - walleye	6	3.4
Mixtures	9	5.0
	179	

Table 6. Macrozooplankton of the Turkey Lakes with approximate indication of their abundance.

Species Found	Batchawana Lake North	Batchawana Lake South	Wishart Lake	Little Turkey Lake	Turkey Lake
Calanoids					
Diaptomus minutus	D	D	D	D	D
Diaptomus sicilis			+		
Diaptomus leptopus	+	+	+	+	+
Epischura lacustris	+	+	+	+	+
Senecella calanoides			+		+
Cyclopoids					
Tropocyclops prasinus mexicanus	D	+	D	D	+
Cyclops scutifer	+	+	+	D	D
Cyclops biscuspidatus thomasi		+	+	+	+
Mesocyclops edax	+	+	+	+	+
Orthocyclops modestus	+	+			+
Cladocera					
Bosmina longirostris	D	D	D	D	D
Eubosmina coregoni				+	
Diaphanosoma brachyurum			+		
Diaphanosoma birgei	D	D	D	D	+
Daphnia pulex	D	D	+	+	+
Daphnia dubia	+	+	D	D	+
Daphnia galeata mendotae	+	+	+	D	+
Daphnia catawba			+		
Daphnia retrocurva			+		
Holopedium gibberum	D	+	D	+	+
Chydorus sphaericus			+		

D = Dominant or numerous at some time in year.
\+ = Present in lower numbers at some time in year.

Table 7. Basic forest dimensions by vegetation type, Turkey Lakes Watershed, Ontario

Vegetation Type	Coverage %	Stocking Stems ha^{-1}	Mean Dominant Height m	Mean DBM cm	Mean Basal Area $m^2.ha^{-1}$	Mean Gross Total Volume $m^3.ha^{-1}$	Mean Gross Merch. Volume $m^3.ha^{-1}$	Mean Total Phytomass $tonnes.ha^{-1}$
<u>Acer</u> <u>Saccharum/Rubus</u>	9.3	845 ± 211	21.0 ± 1.0	17.1 ± 2.6	26.5 ± 6.4	212.3 ± 60.6	203.2 ± 58.1	219.6 ± 54.1
<u>Acer</u> <u>saccharum/Smilarina</u>	56.0	929 ± 245	20.9 ± 1.3	14.8 ± 2.6	24.8 ± 6.5	201.6 ± 59.4	192.0 ± 57.3	204.2 ± 56.3
<u>Acer</u> <u>saccharum-Betula/Taxus</u>	9.3	939 ± 262	19.5 ± 1.8	14.0 ± 2.3	24.0 ± 7.2	202.7 ± 78.7	193.5 ± 75.6	194.5 ± 69.0
<u>Acer</u> <u>rubrum-Thuja/Quercus</u>	13.9	945 ± 295	19.3 ± 2.0	15.3 ± 3.2	26.8 ± 5.0	225.5 ± 50.3	215.0 ± 48.3	205.9 ± 43.0
<u>Picea-Betula/Sphagnum</u>	4.6	1360 ± 448	16.2 ± 2.9	12.6 ± 2.2	25.2 ± 9.3	192.6 ± 76.5	183.2 ± 74.7	153.2 ± 62.3
All others	6.9	961 ± 362	18.8 ± 2.5	14.7 ± 3.2	24.6 ± 8.1	205.9 ± 78.2	195.9 ± 75.1	188.5 ± 77.1

Table 8. Comparison of bioelement concentrations in comparably-sampled oven-dry leaves of sugar maple and yellow birch trees, Turkey Lakes Watershed, Ontario and Hubbard Brook, New Hampshire.

Element	Sugar Maple		Yellow Birch	
	Turkey Lakes[1]	Hubbard Brook[2]	Turkey Lakes[1]	Hubbard Brook[2]
		Per cent		
N	2.16 ± .20	2.19 ± .08	2.91 ± .40	2.78 ± .09
P	.10 ± .02	.18 ± .02	.14 ± .02	.20 ± .00
K	1.00 ± .10	1.01 ± .05	1.50 ± .38	1.14 ± .12
Ca	.81 ± .21	.60 ± .11	.76 ± .08	.88 ± .08
Mg	.11 ± .02	.12 ± .01	.22 ± .04	.25 ± .03
S	.21 ± .03	.21 ± .01	.19 ± .06	.14 ± .01
		$\mu g.g^{-1}$		
Fe	72 ± 7	119 ± 13	93 ± 9	120 ± 8
Mn	900 ± 356	1740 ± 579	1488 ± 411	1920 ± 350
Zn	29 ± 4	52 ± 5	346 ± 86	334 ± 29
Cu	9 ± 2	9 ± 1	11 ± 2	10 ± .25
Na	50 ± 13	16 ± 2	127 ± 15	20 ± 2

[1]Data of Morrison (1985).
[2]Data of Likens and Bormann (1970).