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A Comprehensive Survey of Douglas Lake, Cheyboygan County, MI

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* Win Fairchild in a UMBS lecture stated that D.L. has been slightly eutrophic for 8000 yrs.

Introduction

Freshwater lakes are limited, valuable resources. Lakes provide drinking water for much of the human population, particularly in the Great Lakes region; they are a source of electric and industrial power; they offer extensive possibilities for recreation; they, with their surrounding wetlands, act as natural "kidneys" or purifiers in the water cycle, and, perhaps most importantly, lakes provide habitat and nourishment for diverse, vital ecosystems which cannot be found anywhere else. The study of freshwater lake ecosystems through their natural ontogeny is therefore invaluable and necessary to understand the delicate, incredibly complex balance of factors that create such ecosystems so that they may be conserved and utilized sustainably.

A lake's development over time is primarily influenced by its productivity. Productivity, the rate at which biomass accumulates, depends on the integration of all the components of a lake ecosystem, from the watershed to the profundal zone: its basin morphology, underlying geology and soils, watershed land use, water chemistry, nutrients, and flora and fauna on a macro- and micro-scale. Lakes develop along a continuum from the extremely non-productive, or oligotrophic, to the very productive or eutrophic depending upon their unique makeup of features.

Without knowledge of the natural state of a lake at a given degree of productivity and a profile of its features, it is at best difficult to define what the goal of lake and watershed conservation/management for a lake at that state of development should be. With the objective of developing a full profile of Douglas Lake, Cheyboygan County, Michigan, a comprehensive survey was undertaken. The morphometric parameters investigated were a) the method of basin formation, b) morphometry of the lake basin and littoral zone, c) geology underlying the lake basin and watershed, d) underlying soils of the watershed, e) area of the watershed, and f) watershed land use patterns. Physical parameters measured in Douglas Lake included a) depth , b) temperature and summer thermal stratification, c) depth-dependent light intensity, d) conductivity, e) oxygenation, f) chlorophyll a levels, g) alkalinity/hardness, and h) concentrations of nitrogen, phosphorous, and silica (nutrient richness) by strata. Biotic parameters were surveyed by measuring a) the abundance and diversity of non-benthic phytoplankton, b) abundance and diversity of non-benthic zooplankton, c) diversity of littoral zone macroinvertebrates, and d) diversity of littoral zone macrophytes. The goal of the survey was to measure the basic morphometric, physical, and biotic parameters of Douglas Lake, analyze the surveyed measurements for their individual indications of trophic status, and ultimately integrate all measurements and analyses to create a picture of the lake's overall productivity.

Materials and Methods

The Douglas Lake survey was conducted on July 2, 1997, from the University of Michigan Biological Station (UMBS). All measurements for Douglas Lake were conducted in South Fishtail Bay. Four groups of three students were formed to take four different data sets from the lake. The four groups were responsible for the following measurements: temperature, light intensity, conductivity, pH, dissolved oxygen, chlorophyll a and Gilvin color, alkalinity, hardness, nutrient analysis, littoral zone characterization, and zooplankton/phytoplankton abundance. A collection of macrophytes and macroinvertebrates was also made from the littoral zone. Lake morphometric and watershed parameters were also calculated for both Douglas Lake as a whole and for South Fishtail Bay. Lastly, the trophic state index was calculated for South Fishtail Bay of Douglas Lake.

Lake morphometric and watershed parameters

Morphometric parameters (Wetzel and Likens) were determined using Cricket Graph and a bathymetric map of Douglas Lake and South Fishtail Bay. Watershed parameters were determined using GIS with the aid of Bob Vande Kopple, and a topographic map of the Douglas Lake region. Lake discharge was calculated according to Lind (1979). Characterization of the watershed soils were determined using a soil book of Michigan. The encompassing geology of the Douglas Lake area was determined using a geological map.

Dimensions of the littoral zone

Dimensions of the littoral zone were determined by measuring the distance with a measuring tape from the shoreline to the end of the littoral zone. For the purposes of this survey, the end of the littoral was determined to be located where vegetation was no longer found on the bottom of the lake. Dimensions were taken at four different points in South Fishtail Bay on July 28th, 1997. The Big Shoal of South Fishtail Bay was considered as the north shore for the purposes of the survey.

Temperature

Temperature was measured by standard procedure using the Hydrolab. Temperature readings were taken every 1m, starting at the surface and descending to a depth of 14m.

Dissolved oxygen

Dissolved oxygen was measured using the Hydrolab. The Hydrolab was calibrated against surface water since the surface water reading was assumed to be at 100% saturation. Dissolved oxygen was measured at 1m intervals to a depth of 14m.

Light

Light intensity was measured using two different methods. First, the light meter and probe were used to record light intensity at 1m intervals for 14 meters. The second method consisted of measuring light intensity using the Secchi disk (Welch 1948). For this method, three different readings were taken and then averaged together. The compensation point, defined as being the depth at which light intensity is 1% of the surface light intensity, was determined by calculating the depth of South Fishtail Bay at which light intensity was 1% of the surface light intensity.

Chlorophyll a

Chlorophyll a was measured by collecting Van Dorn water samples from the middle of each layer of Douglas Lake. The middle of each layer of Douglas Lake are at the following depths: epilimnion - 1.5m; metalimnion - 6m; hypolimnion - 11.5m. 125 ml of the water samples were then filtered to retain the algae, and the filters were wrapped in tin foil to limit light exposure of the samples. Once back at UMBS, the filters were given to the UMBS chemist, Mike Grant, who used fluorometeric techniques to determine chlorophyll a levels (standard methods).

pH

pH was measured with the Hydrolab, which was calibrated before taking the pH readings. pH was measured at 1m intervals to a depth of 14m.

Conductivity

Conductivity was measured using the Hydrolab which was calibrated before the measurements were made. Measurements for conductivity were taken at 1m intervals to a depth of 14m.

Alkalinity/Hardness/nitrate/ammonia/total phosphorus/soluble reactive phosphorus/silica

Measurements for alkalinity and hardness (Lind 1979) were determined using similar methods to chlorophyll a. Van Dorn samples were taken from the middle of each of the three layers of South Fishtail Bay. Two Van Dorn samples were taken for each layer of water; one was filtered using a 0.45µm filter (measuring SiO_2, SRP, and dissolved inorganic nitrogen; Standard Methods 1992), and the second sample was left unfiltered (measuring total nitrogen and total phosphorus; Standard Methods 1992). The samples were then given to Mike Grant at UMBS for analysis.

Zooplankton/phytoplankton abundances

Measurements of the abundance of zooplankton (Welch 1948) and phytoplankton (Tuchman 1997 class handout) were taken using a vertical tow net. Depth at which the tows were taken were determined as starting 0.5m above the bottom of the lake. All plankton were then condensed to a known volume and preserved using 200mL of Koechies solution. Three different tows were made at the same depth, but from differing locations around the boat. Abundances were then determined using a compound microscope to count the number of plankton individuals in one transect, and then extrapolating total abundance per liter of water.

Macrophytes/Macroinvertebrates

Macrophytes and macroinvertebrates were collected using dip nets and plant grapples (Lind 1979). The collections were taken from the same locations as the dimensions of the littoral zone were measured, except for the macrophytes because plant material was also taken from Bessy Creek. The data was then identified back at UMBS to the nearest taxonomic level possible.

Trophic status index

The trophic status index for Douglas Lake was calculated according to Carlson (1977). Equations for Secchi depth, total phosphorus, and chlorophyll a were used with our raw data to determine the trophic status index. These equations are the following:

$$\mathrm{TSI\ (SD)} = 10\ [\ 6 - (\ln \mathrm{SD} / \ln 2)]$$

$$\mathrm{TSI\ (Chl)} = 10\ [\ 6 - \{\ (2.04 - 0.68 \ln \mathrm{Chl}) / (\ln 2)\}$$

$$\mathrm{TSI\ (TP)} = 10\ [\ 6 - \{\ (\ln (48/\mathrm{TP})) / (\ln 2)\}$$

Results

Characterization of the lake features

Douglas Lake is of glacial origin. Seven deep kettle holes were formed by the melting of big portions of glacier ice. It is in these holes where the maximum depths are found, leaving the area connecting the holes much shallower. In these shallow areas, big sand shoals can be found. The only outstanding feature is the presence of an island on the southern shore (Fairy Island).

Douglas Lake has only one steady input (Bessy Creek), and one intermittent creek (Beavertail Creek) that was not flowing at the moment of sampling. The discharge rate of Bessy Creek is 0.24 m^3/sec. There are two outputs from the lake: Maple River east branch and the Gorge, which is an underground outflow. The discharge rates of these two outputs is 0.22 m^3/sec for the Maple River outflow, and 0.13 m^3/sec for the Gorge.

Lake morphometry

Several parameters characterizing morphometry were measured for Douglas Lake (Table 5) and for South Fishtail Bay (Table 6), such as surface area, total volume, maximum length and orientation, maximum depth, and shoreline length and development. The characterization of the lake cross-section was done in South Fishtail Bay according to the transect drawn in Figure 1. The littoral benthic zone was 15% of the total area, whereas the profundal zone accounted for 85% (Table 7). In terms of volume, the littoral zone accounted for only 1.10% of the total volume, the difference (98.90%) being accounted for by the pelagic zone (Table 7). The photic and aphotic zone were similarly distributed, with the aphotic zone being slightly bigger than the photic zone (Table 7).

The volume of water in the hypolimnion was significantly higher (average of 2.5-fold) when compared with the volume of the metalimnion and epilimnion (Table 7).

Characterization of the lake watershed

The soil was found to be primarily sandy, but there are areas with loamy sand, muck, and peat soils. Three different types of bedrock characterize the watershed of Douglas Lake: in the NW area, peat and muck are dominant; in the NE, SW, and far NW, the dominant feature is coarse-textured glacial till; and in the SE and rest of the NW area, lacustrine sand and gravel dominate. Douglas Lake has an extensive watershed characterized by many patterns of land use (Figure 6). The immediate border of the lake is characterized by single family or institutional developments and northern hardwoods (411; sugar maple, beech, yellow birch, cherry, and elm). The northeast region of the watershed, which feeds intermittent Beavertail Creek, is an equal mix of northern hardwoods (411), aspen/white birch (413), and lowland hardwoods (414), interrupted by small areas of agriculture (21) and open herbaceous field (31). The northern region of the watershed, north of Munro Lake and the area between and north of Munro and Lancaster Lakes, has large areas of agricultural activity (21) separated by northern and lowland hardwoods (411/414) and a cedar swamp (611) along the upper length of Bessy Creek. This vegetation pattern could be the source of Douglas Lake's lignins and tannins. The western edge of Douglas Lake extending to the southwestern portion of its watershed is predominantly covered by aspen/birch forest (413) as well as fewer lowland hardwoods (414). Moving into the northwest watershed, east of US 31 and south of Levering Road, is a large jack pine plain (42306) surrounded by aspens (413), lowland hardwoods (414), and a large agricultural area (21) near the road. North of Levering road there is extensive agriculture with a few areas of lowland conifer (423) and hardwood (414) interspersed. West of US 31, in the extreme northwest of the watershed, land use is nearly evenly split between agriculture (21), open fields (31; perhaps old agricultural fields) and northern hardwoods (411). In summary, Douglas Lake's watershed can be characterized as relatively pristine stands of aspen/birch and lowland hardwoods close to the lake, limited patches of swamp and northern hardwoods, and further from the lake from the middle to the edges of the watershed, agricultural activity interspersed with northern hardwoods. Agricultural land is estimated to make up less than a third of the watershed.

Physical data and chemical analyses

The temperature profile of Douglas Lake is typical for a summer stratified lake (Figure 2), with a decrease in temperature with depth. The epilimnetic zone is from 0-3 m, the metalimnetic zone is from 4-9 m, and the hypolimnetic zone is from 9-14 m deep (although it can be deeper in some points such as South Fishtail Bay). The dissolved oxygen profile is consistent with the temperature profile (Figure 2), and, at least for the day the sampling procedures were performed, the lake was not anoxic.

Light intensity decreased with depth, with the compensation point being at 9 m (Figure 1). Gilvin color decreased with depth (although this decrease was not drastic), suggesting that the particles responsible for the color were more concentrated on the upper layers of the lake (Figure 1). Chlorophyll a was slightly higher in the epilimnion than in the metalimnion (Figure 1). Surprisingly, chlorophyll a increased in the hypolimnion, to a value very close to the epilimnion chlorophyll a value.

Both pH and conductivity were also measured for the different depths (Figure 3). The change of pH with depth was significant considering pH is measured in a logarithmic scale, whereas conductivity did not change as much. Conductivity increased with depth, whereas pH decreased with depth.

Several other parameters were analyzed such as alkalinity, hardness, nitrate, ammonia, total phosphorus (TP), soluble reactive phosphorus (SRP), and silica (Table 1). Total alkalinity increased with depth in the epilimnion, but remained constant in the meta and hypolimnion. Hardness increased in the metalimnion, but decreased in the hypolimnion to a value similar to the epilimnion value.

Although both nitrate and ammonia could not be detected in the epilimnion, opposite patterns were observed regarding both nutrient concentrations in the meta- and hypolimnion: nitrate increased whereas ammonia decreased, but nitrate increased 3-fold compared to an approximate 1.5-fold decrease of ammonia. Total phosphorus increased slightly with depth, whereas SRP decreased. Since the values for SRP were very close to the detection limit of the instrument with which they were calculated, it is speculated that the lake is phosphorus limited. Silica content increased slightly with depth.

Abundance of organisms

Zooplankton and phytoplankton were abundant in Douglas Lake (Table 2). More than 50% of the zooplankters were rotifers, with *Keratella* and *Kellicotia* being the most abundant genera. Copepod nauplii and *Daphnia* were also abundant, comprising 30% of the total amount of zooplankton. Only one copepod, *Limnocalanus*, was present in large enough numbers in our samples, but it only accounts for 9% of the total zooplankton.

Phytoplankton in our samples were composed of mainly one species of blue-green algae (*Anabaena*), accounting for almost 50% of the total, and the rest of the organisms belonged to only one division (Bacillariophyceae or diatoms). *Tabellaria*, *Aulacoseira*, and *Fragilaria* are all colonial forms abundant in the plankton, whereas *Urosolenia* is often found individually, but it can be found in short chains.

Macroinvertebrates found in Douglas Lake spanned the range of collectors, shredders, grazers and predators, suggesting that there are a lot of microhabitats where they can feed in. Since our sampling of macroinvertebrates was done in South Fishtail Bay, the big shoal was used as the north shore of a hypotetical lake. The big shoal had the least number of organisms and it can be attributed to the fact that the shoal is not a true littoral zone. The south shore was the richest in terms of numbers and diversity (Table 3).

A variety of macrophytes were found in South Fishtail Bay, and even the big shoal (north shore) was really rich in macrophytes, and diversity was even higher than for the south shore (Table 7). The macrophytes found were all angiosperms except for *Chara*, a macroscopic alga that grows in the big shoal and the east shore. All the angiosperms were submersed or emergent, rooted hydrophytes. In order to get a feel for the diversity in a lake as big as Douglas Lake, Bessy Creek was also sampled for macrophytes, and, as it is shown in Table 7, it has almost twice the number of plant families than South Fishtail Bay, suggesting that species richness and diversity are high for Douglas Lake in general.

Trophic State Index Calculation

Values for TSI were obtained based on three different parameters: Secchi disc transparency, total phosphorus, and chlorophyll a. The TSI based on total phosphorus yielded the lowest result (36.32), followed by the value based on chlorophyll a (38.44), and Secchi disc transparency (42.07). Even though the three values were different, they were in the same range.

Discussion

We conclude that Douglas Lake is a meso-eutrophic lake on the basis of its morphometric, physical, and biotic parameters surveyed.

Douglas Lake, according to a bathymetric survey by the University of Michigan's Department of Surveying and Geodesy in 1922, is composed of seven deep holes (from 50 to 80 feet deep) connected by significantly shallower (10 foot deep) shoals (Fig. 7). The connecting shoals enable the transport and mixing of water and its organic/inorganic components between the lake's deep and shallow areas; this allows Douglas Lake to have some consistency in overall profile and therefore allows it to be called one lake. The seven deep depressions have irregular outlines in cross-section (for example, see Fig. 5 - South Fishtail Bay) and very steep sides, indicating that they are kettlehole glacial depressions whose irregularities correspond to the irregularities of the formative ice blocks. Douglas Lake's glacial origin is also shown in the underlying geology of the watershed: the northeast, southwest, and far northwest of the watershed are made up of coarse-textured glacial till.

Glacial morphometry has several effects on Douglas Lake's productivity. This study only includes measurements and data from South Fishtail Bay, a kettlehole of Douglas Lake. However, entire-lake effects can be theoretically hypothesized. A first hypothesis suggests increased overall productivity due to the extensive shallow regions of the shoals. The shoals of Douglas Lake (10-20 feet deep) are within the euphotic zone (to 9 m, or 27 feet) and hence are able to support macrophytes and phytoplankton, increasing productivity. Their shallowness also places the 10-foot shoals within the epilimnion, promoting mixing of benthic nutrients and oxygen, further enhancing shoal productivity.

The productivity of individual kettleholes is also affected. The steep sides of South Fishtail Bay (Fig. 5) decrease the area of the littoral zone dramatically. Shoreline development in South Fishtail Bay is a negligible 1.15 (Table 6), indicating a nearly round body of water, further reducing the area of the littoral zone. The littoral zone ranges 11.8 m from shore on the south edge of the bay, 20.5 m from shore on the west edge, 58 m from shore on the Big Shoal, which was used as the north edge, and 63.5 m from shore on the east edge of the bay. These measurements may appear significant, but the littoral benthic zone comprises only 15% of the entire benthic zone area (Fig. 7). The volume of the littoral zone is only 1.10% of the entire lake volume (Fig. 7). These measurements indicate a severely limited zone for macrophytes and benthic phytoplankton, decreasing their contribution to overall poroductivity. A low macrophyte count is supported by the low numbers and diversity of macrophytes found in South Fishtail Bay's limited littoral zone. A paucity of littoral productivity indicates that productivity would be a) limited and b) primarily planktonic in the kettlehole depressions of Douglas Lake.

South Fishtail Bay's kettlehole formation influences its pelagic productivity through the location of the compensation point, euphotic, and aphotic zones. The Bay is steep-sided and deep (Fig 5). The compensation point occurs at 9 m, while the maximum depth is 20.58 m (Table 6). The euphotic zone occupies 45.50% of the lake volume and the aphotic zone 54.50% (Table 7); therefore, half the volume of South Fishtail Bay is unavailable to productivity of any kind, littoral or planktonic. South Fishtail Bay's deep profundal basin also creates a vast sink for nutrients. The hypolimnion extends from 8-21m while all photosynthetic activity occurs in the epi- and metalimnion; nutrients may therefore be limited in the photosynthetic zone and stored in the aphotic hypolimnion (Fig. 5). Planktonic micropatches of nutrient concentration may be important to pelagic phytoplankton production.

Douglas Lake may benefit from its morphometry in that the maximum length (fetch) of the lake is oriented in the same direction as the prevailing NW-SE winds (Table 6). Prevailing winds may have been a factor in Douglas Lake's formation: the water from large ice blocks, during and after melting, could have been pushed by prevailing westerlies to the southeast, joining Douglas Lake's seven kettleholes to form the contiguous lake. Douglas Lake's coincidence of maximum orientation with fetch allows strong unidirectional waves to build up over the length of the lake, mixing it and distributing nutrients and oxygen to a greater degree than if the lake's fetch were parallel to the prevailing winds. Wind-induced mixing could enhance overall productivity of headwaters and the course of Bessy Creek; this swamp provides much of Douglas Lake's lignin and tannin color, limiting light and decreasing the depth of the euphotic zone. Since South Fishtail Bay's littoral zone is limited and its production is primarily planktonic, light limitation in the pelagic zone could seriously limit productivity. Residential development around the western perimeter of the lake enhances erosion and the input of particulate matter, also limiting light.

In summary, Douglas Lake's morphometric traits are split between those of the kettlehole and those of the shoals. The shoals are very productive areas due to their abundance of light, oxygen, and the mixing action of wind; they provide good microhabitats for flora and fauna. The deep, steep-sided kettleholes, exemplified by South Fishtail Bay, are limited in their productivity by limited littoral zones and an extensive aphotic volume. The lake as a whole has a moderate input of nutrients from the limited agricultural portions of its watershed, increasing productivity, but also an input of particulates, lignins and tannins which would reduce light and productivity. Morphometrically, Douglas Lake has the profile of a meso-eutrophic lake.

The dominant zooplankton in Douglas Lake were rotifers; *Keratella* and *Kellicottia* were the two most abundant genera. These rotifers feed on sedimenting seston particles that bring food close to their mouths by means of a corona of cilia. The particles consumed are relatively small (< 12 μm), so the rotifers probably feed on algal cells of approximately that size. The fact that only large diatoms are present in the phytoplankton could suggest that there is differential ingestion by these genera of zooplankton. It is probably true that since *Keratells* and *Kellicottia* were the most abundant taxa in the zooplankton they must have some competitive advantage with respect to the other taxa. Since *Keratella* is covered by a thickened lorica, and *Kellicottia* has prominent spines it could be possible that these morphological traits confer upon them defense mechanisms against zooplanktivores, therefore releasing them from predation and allowing them to grow in large numbers. This would imply the presence of zooplanktivores as another trophic level (e.g. fish), though this trophic level was not sampled for.

Copepod nauplii larvae accounted for 16% of the total sample indicating a possible bloom. Nauplii were outnumbered only by the rotifers. Only one calanoid copepod, *Limnocalanus*, was present in significant numbers in the samples. Calanoid copepods are herbivores and thus exert control over phytoplankton communities. A cladoceran, *Daphnia*, was also present in relatively high numbers.

Phytoplankton in Douglas Lake were dominated by a cyanobacteria, *Anabaena*. This organism forms long beaded filaments and has the ability to fix nitrogen. Since the relative abundance of *Anabaena* was approximately 50% it could be concluded that by the time of the sampling procedure, the lake was nitrogen limited. This is consistent with the values for nutrient data in epilimnetic waters, where neither NH_4-N (ammonia) nor $N0_3$-N (nitrate) could be detected. The N:P ratio in the epilimnetic zone was 5:1 also indicating extreme nitrogen limitation. It has also been suggested that blue-green algae are often toxic and not palatable to algae feeders, therefore releasing the pressure of predation and thus can grow to large numbers.

The rest of the algal taxa that comprised a significant portion of the phytoplankton were all diatoms (Div. Bacillariophyta), such as *Tabellaria*, *Aulacoseira*, *Fragilaria*, and *Urosolenia*. It is interesting to note that all these genera are multicellular or colonial forms, or have spines. These traits are thought to be beneficial for the algae in two ways: a) they provide with a greater surface-to-volume ratio so that the cells do not sink to the bottom and can thus maximize light absorption, and b) they confer them an advantage as antiherbivore defense. This latter phenomenon could be the result of such abundance of these diatoms in Douglas Lake. In contrast, the absence of smaller, softer, and/or unicellular algal cells may be the result of selective grazing by zooplankton on these more palatable algae. Therefore, the abundant diatom community is the outcome of this differential feeding process.

It is interesting to note that several physical parameters are closely associated with the abundance of organisms. By looking at the dissolved oxygen concentration profile, it can be concluded that the phytoplankton were concentrated in the interface between the epilimnion and the metalimnion (approximately 3-4 m). It is at this depth that a slight increase in oxygen is observed, and it is assumed to be the result of photosynthetic activity by these organisms. The fact that too much solar radiation can cause photoinhibition could explain the location of phytoplankton a couple of meters below the surface of the water since light intensity decreases with depth. On the other hand, zooplankton consume oxygen so it would be logical to assume that they will be concentrated where the oxygen values begins to decrease, although the lake never became anoxic. Studies from previous years suggest that Douglas Lake was anoxic at 15 m (Rekowski 1988, Edlund 1988). The reason could be that the sampling was done late in the summer and also 1997 had a late spring. Bazin and Saunders (1971) though, suggested that historically, in Douglas Lake the rate of loss of oxygen has been increasing, but this pattern was not observed in this study.

Patterns of chlorophyll a were counterintuitive. The concentration of chlorophyll a decreased slightly at the depth associated with the concentration of phytoplankton, and then increased in the hypolimnion. Two hypotheses for this pattern can be proposed: a) since the phytoplankton is dominated by diatoms, and diatoms have both chlorophyll a and c, the concentration of chlorophyll a alone might not be an adequate method to measure algal standing crop; or b) the difference in chlorophyll a values is not significant and is merely due to sampling error.

The pH of the lake decreased drastically from the epilimnion to the hypolimnion. This is consistent with the fact that in the epi-metalimnion interface, where the phytoplankton are located, there is a slight elevation in pH. This could be explained by the fact that use of CO_2 for photosynthesis makes the pH increase. The values of hardness for Douglas Lake make it a hard water lake, suggesting that it has a high buffering capacity. Increases in acidity should be buffered by the carbonate ions dissolved in the water column. This was also concluded by Edlund (1988) who also found pH and hardness values similar to the ones in this study and to studies from 1920-40's. This stability in the values suggests that Douglas Lake possesses a good buffering capacity against acid rain inputs.

All the parameters discussed above also correlate with the availability of phosphorus, nitrogen, and silica. Total phosphorus increased more from the metalimnion to the hypolimnion than from the epilimnion to the metalimnion, suggesting that there is abundant phosphorus locked up in organic material at depths where phytoplankton and zooplankton occur. On the other hand, soluble reactive phosphorus (SRP) decreased with depth, suggesting that closer to the epilimnion-metalimnion interface soluble phosphorus is being taken up actively by planktonic organisms. Nitrogen as nitrate and ammonia were not detected in the epilimnion. The growth of *Anabaena* reinforces the notion that at the time of sampling, Douglas Lake was nitrogen limited. Nitrate increased from the metalimnion to the hypolimnion suggesting that there is decomposition in those layers. As the lake was oxygenated for all its depth, the values for nitrate are higher than the values of ammonia for the same layer, suggesting that some of the ammonia is oxidized to nitrate. Edlund (1988) found that nitrate levels decreased with depth, but this was due to the fact that Douglas Lake was anoxic at the time of Edlund's study. Silica increased with depth, and the epilimnetic layer shows the lowest value. According to Edlund (1988), the increase in the silica level in the hypolimnion is due to "sedimentary flux" and frustule dissolution. Diatoms in the phytoplankton usually take up silica for frustule formation (Schelske and Stoermer 1971) and this could explain the lower numbers in the epilimnetic zone, since Douglas Lake phytoplankton was dominated by diatom genera.

The littoral zone of South Fishtail Bay is not very extensive, but it is rather diverse regarding macrophytes and macroinvertebrates, and supports a benthic food web that accounts for much of the energy recycled in this portion of the lake. Macrophytes provide a good substrate for algae colonization and therefore create a diversity of microhabitats for other organisms to live in. The macrophytes were either submersed or emergent, and they grew fairly deep in the littoral zone. It is speculated that this was due to the depth of the compensation point. Besides from macrophytes, a macroscopic alga (*Chara*) was observed growing mainly on the big shoal.

The majority of the macroinvertebrates are insects and they are classified as predators, collectors and shredders. This diversity in functional groups is indicative of a well represented food web, with each category being important in the conversion and flow of energy in the lake benthic food web. There is also a high proportion of detritus and this is reflected by the high numbers of detritivores (e.g. amphipods). The south shore was the most diverse one and this could be due to the fact that the prevailing northwest winds blow to the south, thus aiding in the mixing of the water nutrients, oxygen, and particles at the southern edge of the lake. This was also suggested by Edlund (1988).

Since the littoral zone has more diversity it could be assumed that productivity is greater in the littoral zone than in the pelagic zone. Even if plankton is abundant, on a square-meter basis the plankton is more dispersed, so the planktonic food web should be less productive. Nevertheless, the productivity of the whole lake could be more influenced by the productivity of the planktonic food web because the littoral zone is a small percentage of the total lake volume.

The trophic status index of Secchi depth measures the degree to which a lake is eutrophic by measuring how light-limited it is. On a scale of 0-100, Douglas Lake's value of 42.07 indicates a mesotrophic, moderately light-limited lake, assuming that 0 Secchi disk transparency TSI is oligotrophic and 100 Secchi disk TSI is eutrophic. Light can be limited by several factors, most significantly a) water color (Gilvin color), where light is absorbed increasingly with increasing concentration of lignins and tannins, and b) particulate matter, including phytoplankton, zooplankton, and suspended debris. The Gilvin color analysis of Douglas Lake revealed moderate levels of lignin/tannin color, with a maximum absorbence of 0.26 units; color is therefore reducing light to a moderate degree. More importantly, light limitation can be shown to be a factor of productivity and particulate lake matter—which is the case with Douglas Lake—specifically phyto- and zooplankton. Douglas Lake's DO curve is a clinograde curve, where oxygen levels decline steadily beyond the euphotic zone, indicating a fairly high level of respiration and productivity by aphotic zooplankton and bacteria. Zooplankton productivity, as demonstrated in a heterograde DO curve, is dependent upon the primary level of production of phytoplankton in the euphotic zone since organic detritus in Douglas Lake is primarily limited to shallower littoral zones. Chlorophyll a data confirms the hypothesis of particulate planktonic matter limiting light. According to these two parameters, moderate light limitation in Douglas Lake could be seen as an indicator of moderate productivity, hence a mesotrophic lake.

The Douglas Lake TP value used for TSI calculation is an average of the TP value for the epi-, meta-, and hypolimnion. Since the trophic status index based on TP measures how productive the lake is, and the TSI calculation equaled 36.32 on a scale of 0-100, we conclude that the lake is a mesotrophic lake. Given that the Secchi disk TSI is 42.07 and Total phosphorus TSI is 36.32, and both index numbers are also within the same range, it could be concluded that Douglas Lake presents an overall level of moderate productivity.

The TSI based on chlorophyll a is 38.44, and this value is also in the same range of the other TSI values calculated based on Secchi disc and TP, reinforcing that Douglas Lake is a mesotrophic lake, but there is still some divergence amongst the three values ("all parameters when transformed to the trophic scale should have the same value", Carlson 1977). Since the TSI values obtained by Secchi disc transparency and chl a are above the TSI value based on TP, we could assume that Douglas Lake is phosphorus limited. Nevertheless, as the TSI value for Secchi disc is higher than the TSI value for chl a, which is itself higher than the TSI for TP, it would follow that primary productivity in Douglas Lake is more limited by phosphorus than by light.

Morphometric characteristics, physical parameters, biotic abundances, and TSI values for Douglas Lake indicate a lake of mesotrophic productivity. Douglas Lake could become more eutrophic in its ontogenetic succession or through agricultural phosphorous loading. However, this survey may prove a valuable tool in designing a conservation program to maintain the natural succession of Douglas Lake.

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Table 1. Douglas Lake (Cheboygan Co., MI) nutrient data for July 2, 1997. TN= total nitrogen; TP= total phosphorus; SRP=soluble reactive phosphorus.

Depth (m)	Limnetic zone	Total alkalinity (mg $CaCO_3$/L)	Hardness (mg/$CaCO_3$/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	TN (mg/L)	SRP (ug/L)	TP (ug/L)	SiO_2 (mg/L)
0-3	Epilimnion	124	128	ND	ND	0.0361	2.7000	7.8500	2.1000
4-8	Metalimnion	135	136	0.0235	0.0155	0.4040	1.0500	9.5500	3.2000
9-14	Hypolimnion	134	127	0.0790	0.0090	0.4660	0.9000	10.5000	4.4000

Table 2. Average absolute and relative abundances of the 5 most abundant taxa of zooplankton and phytoplankton collected from vertical tows in Douglas Lake, Cheboygan Co., MI, on 2 July, 1997. N=3.

TAXA	Absolute Abundance (#/L)	Relative Abundance (%)
Total zooplankton	231	100
Keratella	88	38
Kellicottia	53	23
Nauplii	37	16
Daphnia	32	14
Limnocalanus	21	9
Total phytoplankton	n/d	100
Anabaena	n/d	47
Tabellaria	n/d	20
Aulacoseira	n/d	12
Fragilaria	n/d	8
Urosolenia	n/d	3
Other	n/d	10

Table 3. Macroinvertebrates collected form South Fishtail Bay, Douglas Lake, Cheboygan Co., MI, on 2 July, 1997.

Site	Class	Order	Suborder	Family	Genus
North Shore	Hirudinea				
	Crustacea	Amphipoda		Gammaridae	
South Shore	Hirudinea				
	Crustacea	Amphipoda		Gammaridae	
	Insecta	Diptera		Tabanidae	*Chrysops*
	Insecta	Diptera		Chironomidae	
	Insecta	Diptera		Simuliidae	
	Insecta	Trichoptera		Brachycentridae	*Brachycentrus*
	Insecta	Odonata	Anisoptera	Gomphidae	*Progomphus*
	Insecta	Coleoptera			
	Gastropoda			Planorbidae	
East Shore	Insecta	Odonata	Zygoptera	Coenagrionidae	*Enallagma*
	Insecta	Coleoptera			
	Insecta	Coleoptera		Curculionidae	
	Gastropoda			Planorbidae	
	Gastropoda				
West Shore	Crustacea	Amphipoda		Gammaridae	
	Insecta	Diptera		Chironomidae	
	Gastropoda			Planorbidae	

Table 4. Lake Morphometric and Watershed Parameters for Douglas Lake, Cheboygan Co., MI, on 2 July, 1997.

Parameters	Units
Lake Surface Area	25,603,204 m^2
Total Volume	8.3×10^7 m^3
Max. length/orientation	8025.93 m / NNW-SSE
Max. depth	14 m
Mean depth	3.24 m
Drainage area	60.85 km^2
Shoreline length	29118.19 m
Shoreline development	0.162
Lake area : watershed area	0.42

Table 5. Lake Morphometric and Watershed Parameters for South Fishtail Bay (Douglas Lake), Cheboygan Co., MI, on 2 July, 1997.

Parameters	Units
Lake Surface Area	940,698.56 m^2
Total Volume	12,488,715.88 m^3
Max. length/orientation	1229.85 m / NNW-SSE
Max. depth	20.58 m
Mean depth	13.28 m
Drainage area	nd
Shoreline length	3954.05 m
Shoreline development	1.15
Lake area : watershed area	nd

Table 6. Lake Cross-section data for South Fishtail Bay (Douglas Lake), Cheboygan Co., MI, on 2 July, 1997.

Parameters	Units	%
Area / % total area of littoral benthic zone	1,732,918 m^2	15.00
Area / % total area of the benthic profundal zone	23,870,286 m^2	85.00
Volume / % total volume of the littoral zone	136,665.89 m^3	1.10
Volume / % total volume of pelagic zone	12,352,050 m^3	98.90
Volume / % total volume of the euphotic zone	5,682,061.93 m^3	45.50
Volume / % total volume of the aphotic zone	6,806,653.95 m^3	54.50
Volume / % total volume of the epilimnion	2,487,710.08 m^3	19.20
Volume / % total volume of the metalimnion	3,194,351.85 m^3	25.28
Volume / % total volume of the hypolimnion	6,806,653.95 m^3	54.50
Volume / % total volume above 0 mg/L DO.	12,488,715.88 m^3	100.00

Table 7. Macrophytes from South Fishtail Bay (Douglas Lake), Cheboygan Co., MI, collected on July 2, 1997. (Bessy Creek macrophytes also included)

Site	Family	Genus /species
North Shore	Sparganiaceae	*Sparganium sp.*
	Polygonaceae	*Polygonum amphibium*
	Characeae	*Chara sp.*
	Cyperaceae	*Scirpus sp.*
South Shore	Potamogetonaceae	*Potamogeton gramineus*
	Potamogetonaceae	*Potamogeton amplifolius*
	Hydrocharitaceae	*Elodea canadensis*
East Shore	Hydrocharitaceae	*Elodea nuttallii*
	Potamogetonaceae	*Potamogeton gramineus*
	Haloragraceae	*Myriophyllum sibiricum*
	Potamogetonaceae	*Potamogeton filiformis*
	Characeae	*Chara sp.*
Bessy Creek	Cyperaceae	*Scirpus sp.*
	Potamogetonaceae	*Potamogeton richardsonii*
	Potamogetonaceae	*Potamogeton sp.*
	Iridaceae	*Iris sp.*
	Lemnaceae	*Lemna minor*
	Myricaceae	*Myrica gale*
	Allismataceae	*Sagittaria sp.*

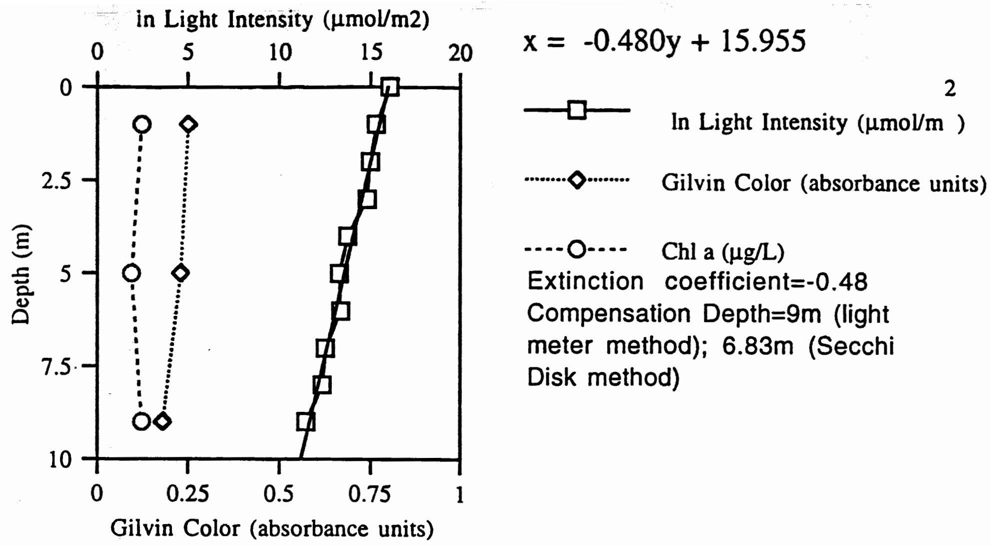


Fig. 1 Vertical profiles of ln of light intensity and Gilvin color for Douglas Lake, Cheboygan Co., MI. on July 2, 1997

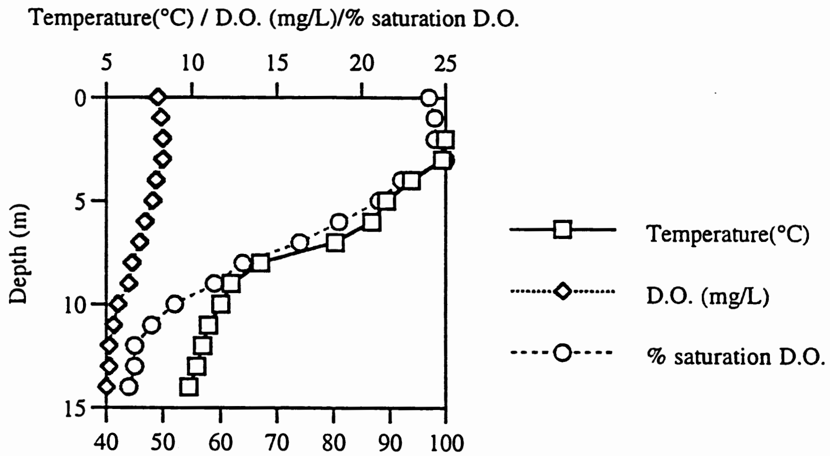


Fig. 2 Vertical Profiles of Temperature and Dissolved Oxygen in Douglas Lake, Cheboygan Co., MI. on July 2, 1997

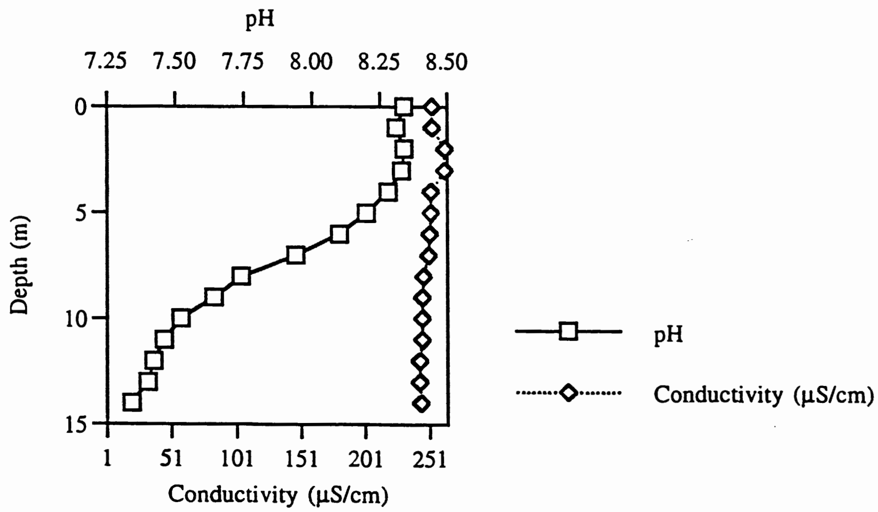


Fig. 3 Vertical profiles of pH and Conductivity for Douglas Lake, Cheboygan Co., MI. on July 2, 1997

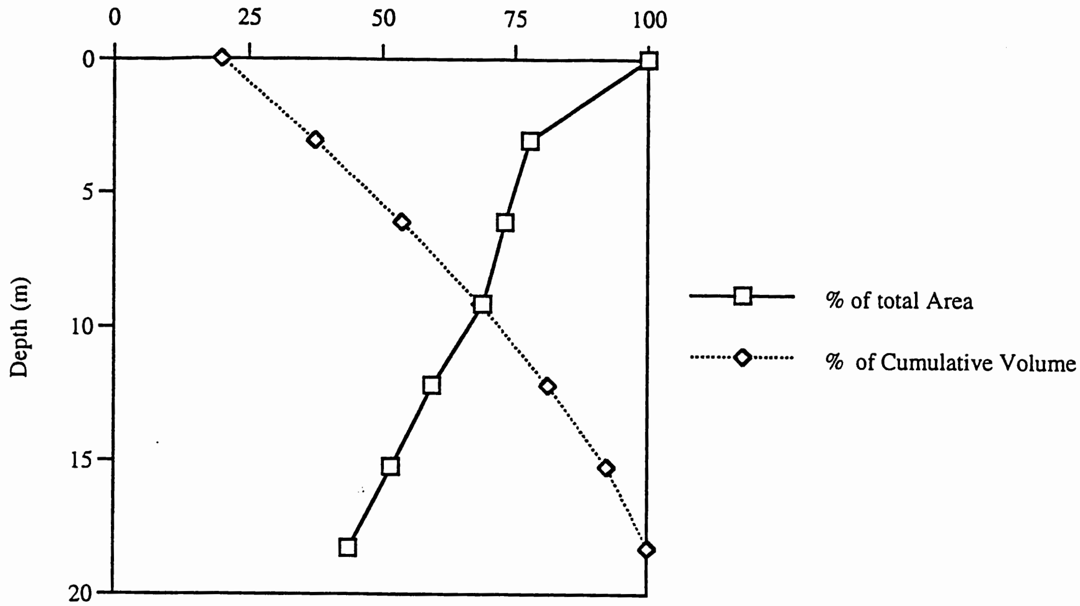
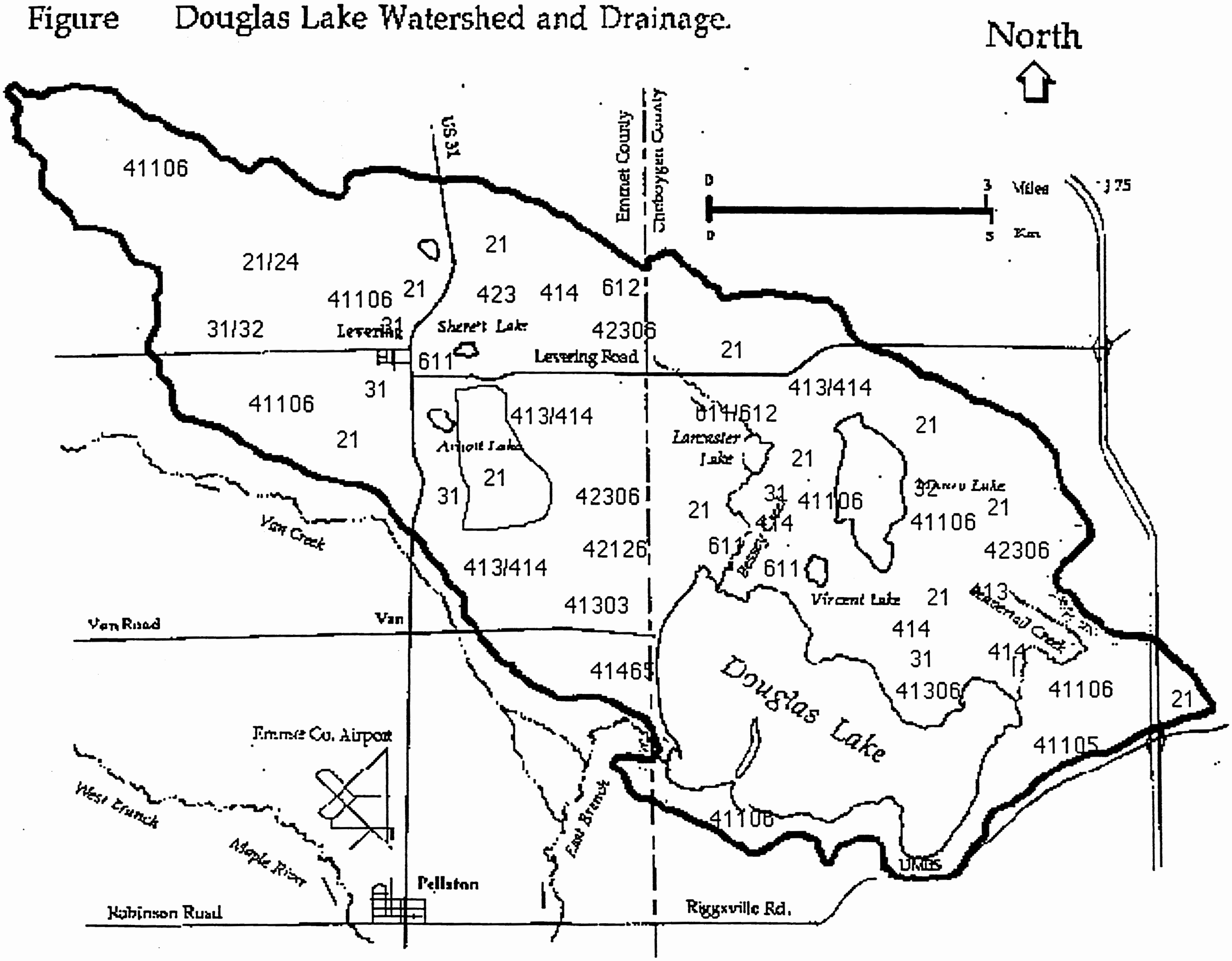


Fig. 4 Hypsograph and volume curve for South Fishtail Bay, Douglas Lake, Cheboygan Co., MI, on 2 July, 1997.

Figure Douglas Lake Watershed and Drainage.



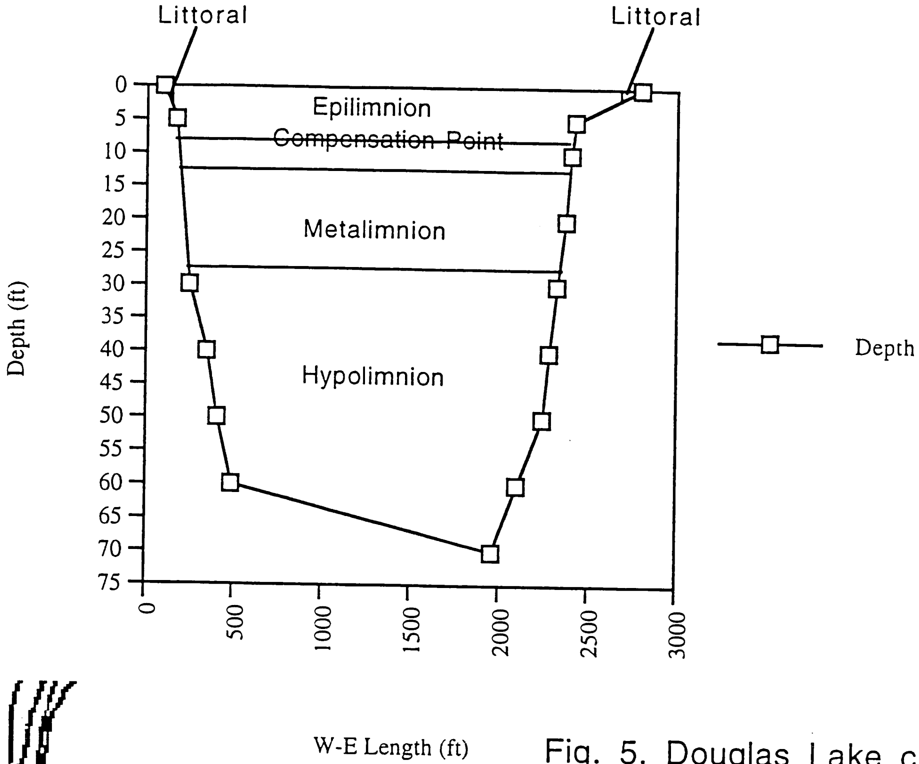


Fig. 5. Douglas Lake cross-section taken on July 2, 1997.