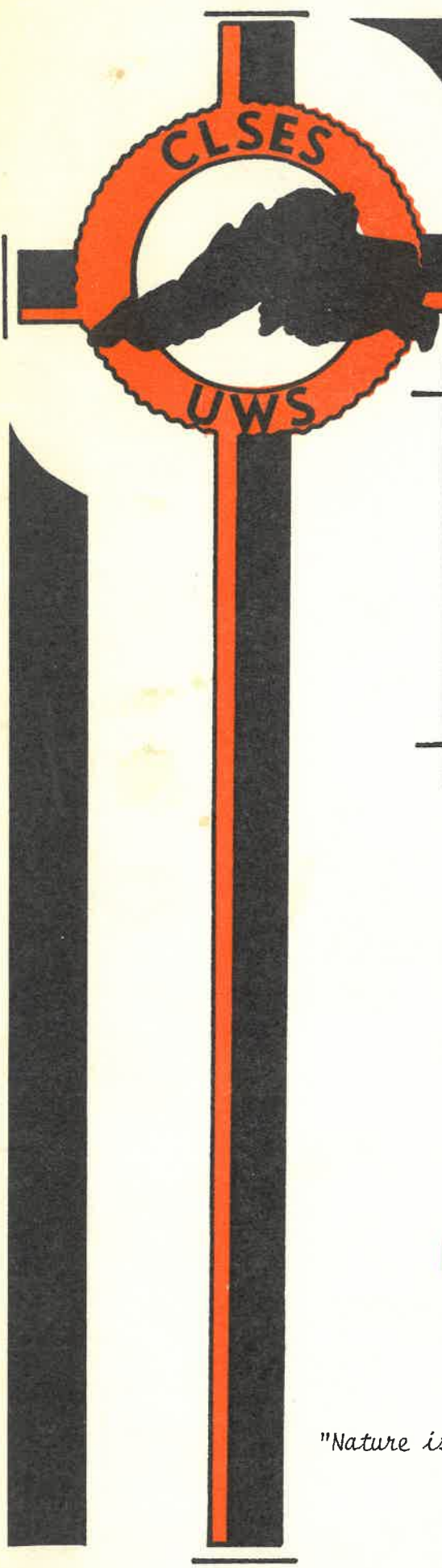


M. Bacon



Characteristics of the
Duluth-Superior Harbor and
Lake Superior

a report by the

**CENTER for LAKE SUPERIOR
ENVIRONMENTAL STUDIES**

of the

**UNIVERSITY of WISCONSIN
SUPERIOR**

"Nature is Often Hidden: Sometimes Overcome, Seldom Distinguished"

*Essays: Of Nature In Men
by Frances Bacon
published in 1597*

TABLE OF CONTENTS

	<u>Page</u>
Characteristics of the Duluth-Superior Harbor and Lake Superior	1
Introduction	1
Duluth-Superior Harbor Area	1
Lake Superior	11
Physical Characteristics	11
Chemical Characteristics	15
Biological Characteristics	17
Geology of the Lake Superior Region	20
Experimental Determination of Oxygen in Water	26
General Considerations	26
Solubility of Oxygen in Water	28
Measurement of Dissolved Oxygen	29
Appendix A Some Common and Average Values for Lake Superior	
Appendix B Key to Lake Superior Zooplankton	
Appendix C Key to Orders of Insects	
Appendix D Key to Fish of Lake Superior	

LIST OF FIGURES

		<u>Page</u>
1	Duluth-Superior Harbor Area	2
2	Bottom Topography of Lake Superior	14
3	Surface Currents of Lake Superior	14
4	Geologic Time-Table	21
5	Major Bed Rock Units, Western End, Lake Superior	22

LIST OF TABLES

1	Water Quality Characteristics of Lake Superior Water	16
---	---	----

CHARACTERISTICS OF THE DULUTH-SUPERIOR HARBOR AND LAKE SUPERIOR

Introduction

The twin ports of Superior, Wisconsin and Duluth, Minnesota were founded at the head of the world's greatest continuous mass of freshwater. The Laurentian Great Lakes contain about 20% of the world's freshwater resources. Half of that water is contained in the largest and most pristine of these lakes - Lake Superior. The tremendous size and purity of this water body make it one of the world's unique aquatic ecosystems. In addition to this resource, the Superior-Duluth harbor is protected by the largest natural inland sand bar in the world. Minnesota and Wisconsin Points, with a combined length of over 9 miles, serve to protect what has become one of the largest and busiest ports in the world. The estuary itself contains over 11,500 acres of water and is fed by many small tributaries and two major river systems, the Nemadji and the St. Louis. The St. Louis River is the largest U.S. tributary to Lake Superior (See Figure 1).

The juxtaposition of the estuary and Lake Superior and the effects of a major port on these water resources have served to create unique and contrasting aquatic environments. Some species populations in these two environments benefit and take advantage of both, while others are segregated by environmental gradients such as temperature or water purity. These interactions, along with other physical conditions restricted to Southwestern Lake Superior, provide a variety of unique opportunities for the study and understanding of the behavior of freshwater organisms.

Duluth-Superior Harbor Area

The Superior-Duluth harbor area is located at the southwestern tip of Lake Superior (Figure 1). The harbor area serves as an economic base for the cities of Superior, Wisconsin and Duluth, Minnesota who have a combined population of 138,000 people.

The harbor consists of two major bays - Superior Bay, the eastern portion and St. Louis Bay, the western end. Superior Bay has a surface

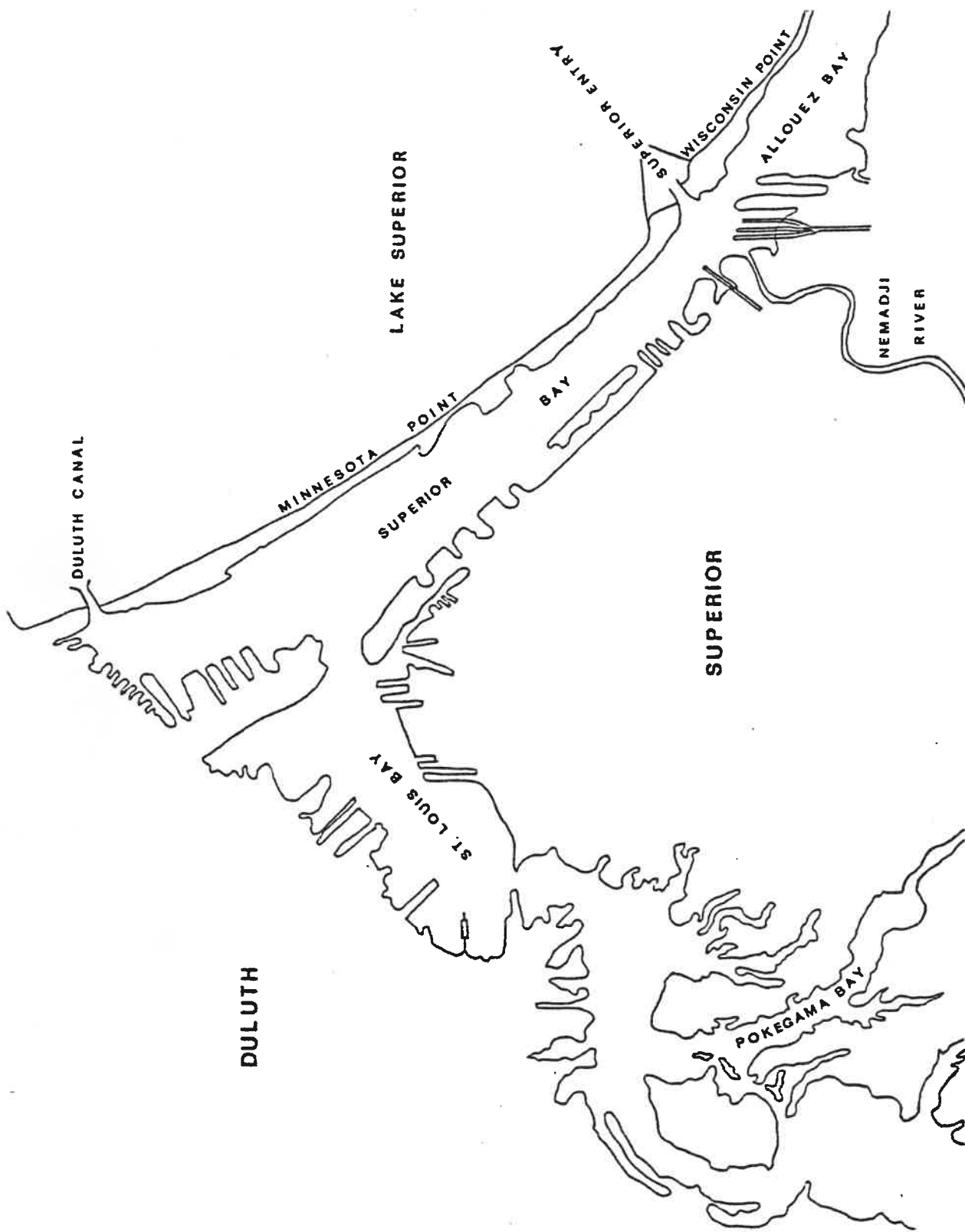


Figure 1. Duluth-Superior Harbor Area

area of 14.3 km² while St. Louis Bay has a surface area of 9.7 km². The St. Louis River discharges into the St. Louis Bay with an average flow of 64.3 m³/sec.

Minnesota and Wisconsin Points were formed largely through wave action depositing sand due to prevailing northeasterly winds. Originally, the only outlet to Lake Superior was the Superior Ship Canal (or Superior Entry). This canal separates Minnesota and Wisconsin Points. In 1871 work was completed on the Duluth Ship Canal which provided a second access between the harbor area and Lake Superior. The natural depth of the harbor in channel areas is from 2.4 to 2.7 m but dredging is carried out periodically to maintain the depth of the main channels between 8.2 and 8.5 m.

The bottom sediments generally consist of recently deposited clay, silt and peat which average about 3 meters in depth. Beneath this upper layer lies a thicker bed of sand and hard clay.

The two main bays of the harbor retain water for relatively short periods. The retention time of water in the St. Louis Bay is about 6 days while in the Superior Bay area it is 8 days. There are periodic flows of Lake Superior water through the Superior Bay particularly during times of northeasterly winds. Thus Superior Bay is flushed with high quality Lake Superior water.

Primary activity within the harbor relates to shipping activities. Large amounts of taconite tailings, coal and grain are transported to other ports. There are 39 major docking facilities. The dredged channels in the harbor area are 27.4 km in length. An average of 125,000 m³ of sediment must be removed from the harbor each year to maintain channels and docking areas.

The water quality of the harbor area is largely influenced by municipal and industrial discharges and wastes from shipping activities. Historically, water quality problems resulted from discharges to the St. Louis River, the St. Louis Bay and Superior Bay from inadequately treated municipal waste, effluent from paper processing plants, effluent from a steel mill, discharges from wood product manufacturing plants and ship wastes.

Currently, water quality is improving with the upgrading of the quality of point discharges and the incorporation of a number of effluents into the Western Lake Superior Sanitary District Waste Treatment Facility which began operation in 1978. However, waste ballast water, tanker-hold clean out wastes

and oil and grease from ship operations are uncontrolled.

Previous water problems have centered on low oxygen levels (particularly in the St. Louis Bay area), high levels of phosphorus, copper and phenolic type compounds. The phenolic type compounds have produced taste and odor problems in fish which seem to be dissipating as water quality improves.

Before beginning a discussion of some of these unique aspects of the Superior-Duluth estuary, it will be useful to briefly examine the general structure of aquatic communities. Any ecosystem, be it terrestrial or aquatic, must obviously rely on the primary producers (plants) to support all of the higher level consumers. The primary producers are considered the lowest "trophic level". Organisms which feed on the plants are termed "primary consumers". Those feeding on primary consumers are "secondary consumers", and so on until the top order predator in the food chain is reached. Conversion efficiencies from one trophic level to another is often approximated to be about 10%. In other words, it takes 100 pounds of plant material to produce 10 pounds of primary consumer, which in turn is eaten to produce one pound of a secondary consumer (such as a smelt in an aquatic system). If the smelt are then eaten by large trout, it will have taken 100 pounds of plant material to produce one tenth of a pound of trout! The primary producers must therefore constitute by far the largest biomass of any group in the ecosystem and factors affecting this level of production are felt throughout the system.

The plants which provide this level of production in aquatic systems may come from a variety of sources. In streams the main source of plant material is leaf fall, twigs, etc. which are produced terrestrially. In lakes primary production takes place almost entirely within the lake system itself. Primary producers within the lake can again be subdivided into two major groups. The rooted aquatic plants (often called macrophytes) are the most familiar and include emergent plants such as cattails, wild rice, reeds, or arrowhead and submerged plants, such as pondweed and elodea. The rooted aquatic plants can be seen to play a major role in the estuarine environment while they are practically nonexistent in Lake Superior proper. The second major group of primary producers in lakes is the phytoplankton. In most

aquatic systems one of the most important assemblages of organisms is the plankton. Plankton includes plants (phytoplankton) and animals (zooplankton) which range in size from microscopic to about one centimeter. They are free-swimming or free-floating in the water column. Phytoplankton includes small unicellular or filamentous algae. The most familiar algae to most people is the floating algae most commonly called pond "scum". Most types of phytoplankton, however, are not floating at the surface, but occur within the water column. It is this group which is usually the most important to the ecosystem in terms of maintaining oxygen levels in the water and providing a food source for all of the higher orders of animals. Like all plants, phytoplankton is very responsive to light levels, temperature, and nutrients, and their total abundance and distribution within the water column is largely dependent upon these parameters.

Zooplankton constitute the remainder of the planktonic organisms in aquatic systems (See Appendix B). The major groups of organisms composing the zooplankton are the rotifers (Phylum Rotifera) and the cladocerans and copepods (Phylum Arthropoda, Class Crustacea). These small animals range in size from 40 microns to 18 mm and are a major food source for many of the young of fish such as walleye, yellow perch, northern pike, and many others. They also serve as the primary food source for larger fish which filter the water for food, such as lake herring and pink salmon. Many of the zooplankton feed on the phytoplankton or on microorganisms. Others are predaceous and feed on other zooplankton.

Zooplankton tend to exhibit marked migration through the water column on a daily basis. The general tendency is to maintain positions which are fairly deep during the day and much closer to the surface during the night. These tiny creatures have been shown to swim actively towards the surface at a rate of 10 m/hour. This daily pattern of migration has evolved due to a variety of factors, perhaps related to avoiding fish predation by hiding in deep water during the day and moving to the surface at night to feed where phytoplankton is more abundant.

The organisms which live in the bottom sediments are known collectively as benthic organisms. A variety of groups are found here, but the most common are the insects (see Appendix C) (Phylum Arthropoda, Class Insecta),

oligochaetes (Phylum Annelida, Class Oligochaeta), which are related to the earthworms, a few crustaceans (Phylum Arthropoda, Class Crustacea), some nematodes (Phylum Nematoda), and clams (Phylum Mollusca, Class Pelecypoda). These organisms provide the primary food source for a number of our major game and commercial fish species (e.g. whitefish and young trout and salmon) as well as small fish which serve as food for the larger fish. Benthic organisms can be quite numerous in aquatic systems, though most people are aware of them only when there are large hatches of some of the more abundant insects with terrestrial adult forms. Work in streams tributary to Lake Superior demonstrated densities as high as 3200 individuals in one square foot of stream bottom! Densities are generally lower in lakes, but it is not uncommon to find 200-300/sq. ft.

The benthic organisms are often used as indicators of pollution. Some of these organisms are adaptable to very low oxygen levels or other types of pollutants which impose some stress on the system. A 'healthy' system with few limiting factors is generally characterized by many different kinds of benthic organisms with few individuals of each kind. A more polluted situation may actually have a higher total number of individuals, but many fewer species of organisms. These species are termed "pollution tolerant", and, though very abundant, are often not desirable types in terms of usefulness as a food item for fish and other organisms.

The aquatic organisms most familiar to almost everyone are fish (see Appendix D). If thought of in terms of their contribution to the biomass and total energy flow through the aquatic ecosystem, they actually assume a relatively minor importance. They are, however, by far the most important economic group and management of aquatic ecosystems is often geared towards maximizing production of the more desirable fish species.

Fish occupy a large variety of aquatic habitats. They may be pelagic (free-swimming in the water column) or more associated with the bottom. They may eat plankton, plants, insects, or fish. They may prefer weedy areas, or rocky areas, or even sandy areas. These food and habitat preferences vary, of course, depending on the species of fish, but they also change due to physical and chemical conditions of the water, between night and day, and

as the fish grows from the fry through the adult stage. The complexities of their distribution and the difficulty in observing fish behavior often necessitates fairly intensive sampling efforts over a period of time with a number of types of gear before a reasonable understanding of behavior and distribution can be achieved.

Estuaries are by their nature very productive and complex systems. Many people consider that, by definition, estuaries occur only where a river runs into an ocean or sea and the salt water-fresh water interface establishes the specific conditions of the estuarine environment. Similarities between the behavior of organisms, the general physical conditions of depth and vegetation, and the high rate of production, however, have brought more recognition to those bodies of water which could be considered true fresh-water estuaries.

Estuaries are generally formed in drowned stream valleys, that is river mouths where the land is submerging over geologic time. That is exactly what is occurring in the Superior-Duluth area. As a result, this drowned river mouth is greatly affected by changing lake levels of Lake Superior which can be caused by very small tidal effects, but primarily by "seiches". Seiches are caused when a sustained wind or change in atmospheric pressure "piles up" the water at one end of the lake. As the wind subsides the piled water runs back toward the lower surface. This back and forth oscillation may continue for some time. A seiche may cause a daily change in water levels in the estuary of up to 1.5 feet. This would have obvious effects in terms of changing water temperature as the cold lake water is pushed into the warmer estuarine water. It would also result in the stranding or submergence of some of the important shallow water habitats.

Estuaries are characterized by broad shallow expanses of water, fairly high nutrient levels (compared to the large body of water which they adjoin), and large areas of emergent vegetation. All of this certainly holds true for the Superior-Duluth estuary. Prior to the advent of shipping and dredging, the maximum depth in the 11,500 acre estuary was about 9 feet. The large undredged open water areas such as Allouez Bay (1050 acres) and Spirit Lake (850 acres) still have maximum depths of 6-7 feet and average depths of 4-5 feet.

The river water is relatively warm compared to Lake Superior and the broad shallow reaches allow the water to warm even further during the summer months. The warm water and the nutrients from the river watershed and from urban sources combine to create conditions for higher rates of plankton production (both phytoplankton and zooplankton) than are found in Lake Superior. Temperature is very important in dictating not only rates of growth of different organisms, but also which organisms might do best and how much food is necessary for survival and growth.

The warmer temperatures and higher nutrient levels in the estuary result in a different assemblage of phytoplankton than might be found in Lake Superior. The prevalent group of phytoplankton in Lake Superior is the diatoms. These are the best adapted algal group to low water temperatures, low nutrient levels, and low light levels. The diatoms are basically unicellular algae with silica shells and occur in a variety of interesting shapes. As water temperatures and nutrient levels increase, the tendency is for the diatoms to be replaced by green algae and eventually blue-green algae if there is further nutrient enrichment. The harbor and estuary are warmer and contain more nutrients, and it would be expected to find more of the green algae, and perhaps blue-green, than would occur in Lake Superior.

Similarly, there are differences in the types of zooplankton which occur in the two environments. The crustacean zooplankton are the most important major group and comprise the majority of the zooplankton in most aquatic systems. The major sub-groups of these zooplankton are the cladocerans and the copepods. The cladocerans are generally weaker swimmers and often feed by grazing on algae and microorganisms which grow attached to plants. The copepods are often stronger swimmers and rely more on filtering the water column for the phytoplankton and microorganisms. As might be expected in comparing the shallow, weedy estuarine environment to the open lake environment, the grazing cladocerans are more common in the estuary and the filter feeding copepods in Lake Superior.

The estuarine environment offers a much more diverse physical environment (deep and shallow, weedy and weed free, etc.) and the zooplankton, as well as other groups of organisms such as fish and insects, have a wider variety of habitats than would be found in Lake Superior. More habitat types

provide more "niches", resulting in a wider variety of zooplankton, insects, and fish in the estuary.

Another condition which is fairly specific to the Southwestern area of Lake Superior is red clay turbidity in the water. This occurs in both the estuary and the lake and provides interesting conditions for the examination of the effects of turbidity and reduced light penetration on the distribution of phytoplankton, zooplankton, and fish. Specific areas of the estuary, such as the Nemadji River, Allouez Bay, and Pokegama Bay persistently exhibit this type of turbidity. Distinct plumes of red clay turbidity often occur where the Nemadji runs into the harbor. Comparison of the vertical distribution and abundance of zooplankton between the clay plumes and adjacent harbor waters yields some very interesting observations on their behavior in the two areas.

The benthic fauna can serve as a major food source for many fish species. Benthic organisms, or those organisms living on or in the bottom sediments, can be extremely numerous and quite variable in species composition. Much of the sediment in the estuary and harbor as well as Lake Superior is a fairly uniform mixture of muck, clay, and sand. This may support a large number of organisms, but it is not a varied or diverse type of habitat. If we again consider as a rule of thumb that a diverse habitat allows a larger variety of types of organisms, we might suspect that the uniform sediments will have only a few types of benthic organisms. If, however, samples were taken in rocky areas or areas with vegetation, it would probably be found that a much more diverse group of organisms was present. Because the estuary has such a variety of habitats and large amounts of vegetation and rocky areas in the upper reaches, the abundance and diversity of benthic fauna is generally much greater than that in Lake Superior.

Estuaries around the world are important areas for reproduction of the fish from the large bodies of water which they adjoin. Because of the shallow weedy habitat, the high plankton populations, and the generally high productivity, they are also important as nursery areas for the young fish after they hatch. This is again true of the Superior-Duluth estuary. A number of fish which reside primarily in the lake spawn in the estuary. Walleye, rainbow smelt, brown and rainbow trout, spottail and emerald shiners, and four

species of suckers move annually into the estuary to utilize the excellent spawning habitat. The walleye, for example, concentrate from about 80 miles of Lake Superior shoreline to spawn in only about 1.5 miles of the St. Louis River! After the young of the aforementioned species hatch, they are all pelagic (free swimming in the water column) for at least their first month of life. At this time they feed on zooplankton. The abundance of the estuarine zooplankton make feeding and growth much more efficient than if they had to begin life in the cold, relatively sterile Lake Superior waters.

The abundance of minnows and young fish feeding in the estuary provides a good food base for temporary residence of species which live primarily in Lake Superior as well as those which live in the estuary throughout their lives. The estuary provides shallow water habitat which is much warmer than the lake during the summer months. These conditions are preferred by such species as the yellow perch and northern pike. Although these fish may make temporary forays into Lake Superior, they thrive in the estuary and provide an outstanding sport fishing potential.

The complexities of the biologic systems in the estuary have been further confounded by problems with water pollution. The physical conditions which make estuaries so productive have also made them the most attractive areas for ports and industrial development. Many of the world's largest and most productive estuarine areas have suffered from water quality problems, and even more seriously from habitat destruction due to dredging and filling. Improvements in water quality, it is being found, can result in almost complete recovery of the aquatic populations which inhabit the area. Habitat loss is often a final blow and many important estuarine areas have been lost forever.

Luckily most of the habitat components which have made the Superior-Duluth estuary so productive are still intact today. Increasing attention to pollution abatement is bringing today's water quality to a level which has not been realized for almost a century. The area is about to return to the productive potential which its habitat promises, and the Superior-Duluth area will continue to boast of one of the world's great inland estuaries.

Lake Superior

The Great Lakes provide what is sometimes referred to as the fourth coast of the United States. They differ from the oceans in that they are freshwater. Of the five Great Lakes, Superior is the largest, the purest and the most important. Sometimes described as a water "desert", Lake Superior is a very delicate lake. It is important that it remain in its present pure state. Its main importance is that it is the major water source for the other Great Lakes, that is, clean Lake Superior water flushing the others, which have lower water quality.

PHYSICAL CHARACTERISTICS

Since 1922 the level of the lake has been regulated by control works in the St. Mary's River at Sault Ste. Marie, Michigan. These works are directed by the International Lake Superior Board of Control, consisting of representatives from the U.S. Corps of Engineers and officials of the Canadian government. The function of the Board is to determine the amount of water available for power generation at the Soo and to maintain the level of Lake Superior at an elevation of 600 feet. Present lake levels are close to the 100 year high level of 602 feet. Water levels are lowest in March or April and highest in August. Winds blowing consistently from a single direction for several days produce greater apparent changes in the water level, although these last for only short periods and may be entirely reversed within a period of a week. Changes in atmospheric pressure accompanying the passage of weather fronts over the lake sometimes generate seiches which are rapid, general rises in lake level. Such effects have been felt particularly at Bayfield and elsewhere along the shores of Chequamegon Bay, and were noted by the early explorers of the region.

Lake Superior is the world's largest inland lake. It is located in an area where even small lakes are relatively unproductive due to the cold temperatures and relatively sterile soil conditions which exist in the watershed. The sterile soils, low rate of human development and human pollution, the deep waters, and the cold climate and water temperatures combine to make the lake not only the largest but one of the purest of the world's lakes.

The purity of the lake is indicated by the transparency of the water which characterizes much of the lake. The southwestern portion is relatively turbid due to red clay erosion, but in the more central portions of the lake objects lowered into the water can be seen to a depth of 60 feet. This is possible only because of the very low density of zooplankton and phytoplankton. Production of these organisms is restricted by the low nutrient levels and the low water temperatures.

Over 40 years ago James Merrill (Wonderland of Lake Superior) wrote "Lake Superior is the most striking feature of the interior of the continent of North America". Elsewhere, he states, ". . . the size of this great lake is the least of its attractions. Its waters are clear as crystal . . . its color is azure blue in the deepest parts and an emerald green near the banks where it glimpses and reflects the vegetation of the shore". Today, if we were to travel around Lake Superior, some inshore areas of highly turbid waters can be seen, areas which have been affected by man's activities. Other less obvious changes may also have occurred to the water quality of Lake Superior.

The present Lake Superior has a length of about 350 miles and a maximum width of about 160 miles, giving it a surface area of 31,280 square miles - i.e., the lake is about the same size as Scotland. The maximum measured depth of the lake is 1,333 feet and the average depth is 480 feet, giving a volume of about 3,000 cubic miles. Charts show the bottom of the western part of the lake basin is rather smooth, in contrast to the strong north-south valley and ridge topography of the eastern half (see Figure 2). The valley system is interpreted to be of stream origin, somewhat modified by glacial action. The topography of the eastern basin is controlled by bedrock only thinly mantled by glacial and post-glacial sediments. In the western basin the young deposits are several hundred feet thick, more or less completely mantling an equally rugged bedrock topography. The thickest deposits lie along the Minnesota side of the lake, where as much as 1,000 feet of sediments overlie the bedrock. On the basis of a limited amount of core sampling the sediment sequence can be shown to lie on a sandstone basement, above which are a complex of clayey to bouldery glacial tills alternating with sandy outwash deposits and clays, followed by lake sediments which are crudely layered and contain interbeds of sand. The older parts of the clay sequence are seasonally

layered (varved), while the younger parts of the sequence are more massive in character and contain fragments of wood.

Water circulation in the lake is controlled by prevailing wind directions and by temperature. The principal circulation of the waters in the western part of the lake is in a counter-clockwise direction, although toward the center of the lake a complex eddy effect is to be observed off of the Bayfield peninsula and the Apostle Islands and complex counter currents exist close to shore as noted in Figure 3. Water movements are influenced by the formation of thermoclines - zones of rapid temperature change between two layers of water which differ in temperature and density.

Because Lake Superior is in the northern tier of the U.S., it is subject to major seasonal changes in air temperature and radiation. The large size and great depth (maximum 406 meters, mean 148 meters) gives the Lake a relatively long thermal response time and its annual temperature cycle lags behind that of air and land. The result being a moderating influence on the climate of the coastal regions.

The Lake is dimictic - that is - it undergoes vertical mixing at 4°C (density of water greatest at this temperature) twice a year. It also exhibits thermal stratification. Lake Superior is slower to develop a thermocline, when compared with other Great Lakes, stratifying usually in late July and then only near shore. The upper layer of the stratified water column is called the epilimnion while the deeper waters remain cold creating a hypolimnion. The middle portion shows little stratification until well into August and a sharp thermocline seldom develops. Nearly 95% of the lake's volume is in the hypolimnion year round. Fall turnover occurs in stratified regions in early December, and the lake then cools to 1-2°C. Ice forms late on Lake Superior and normally does not freeze over completely due to the large size and storms that occur.

The lake temperature is of great interest. The Lake remains very cold, near 4°C (39°F) during most of the year. This coldness can hinder or at least slow down the ability of the Lake to correct a chemical problem, thereby making the lake more susceptible to pollution. Some pollution problems are eliminated naturally under the right conditions; cold temperatures may slow some of the natural processes.

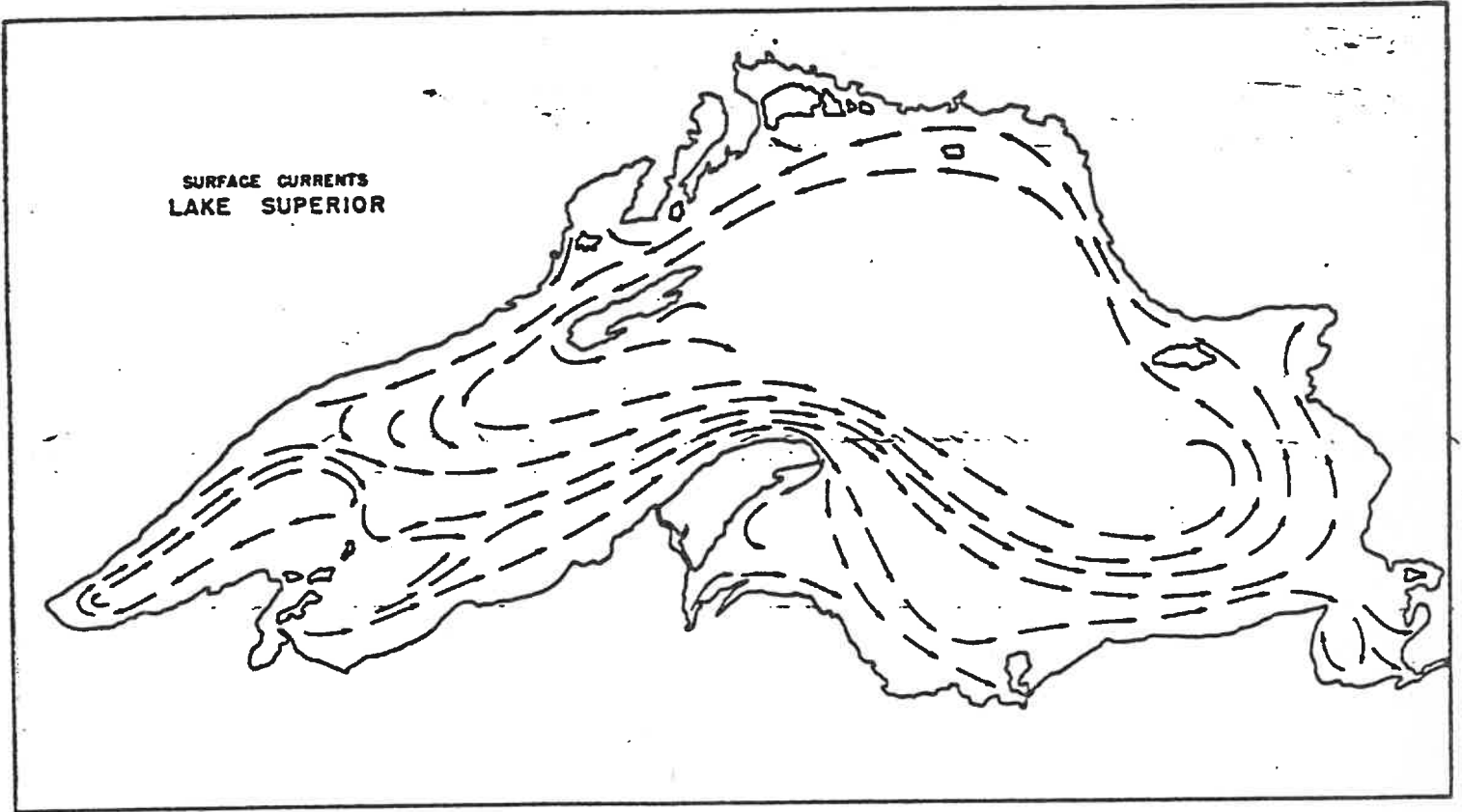


Figure 3 Surface Currents of Lake Superior

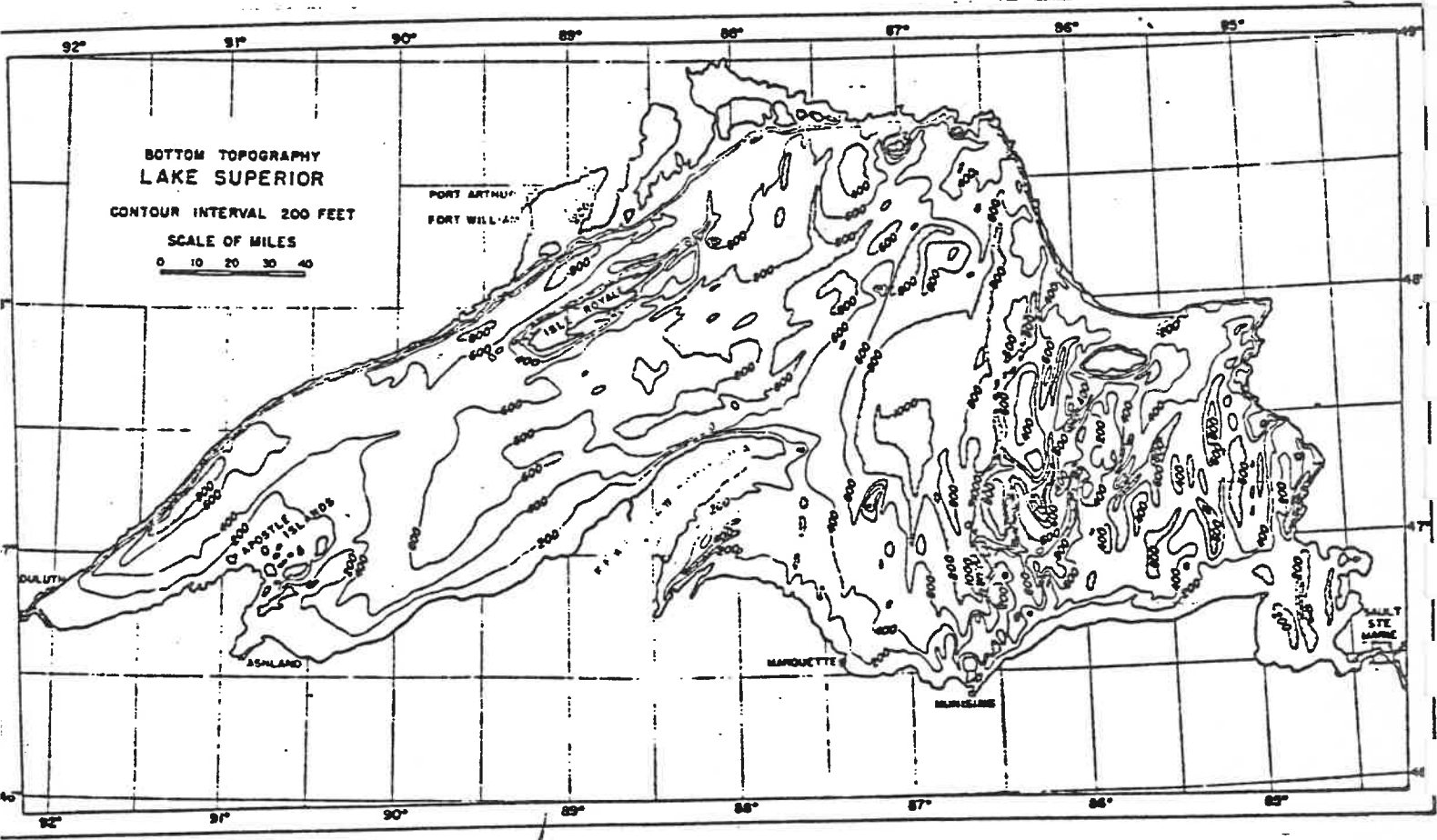


Figure 2 Bottom Topography of Lake Superior

CHEMICAL CHARACTERISTICS

At the present time, the Lake is relatively pollution-free with the exception of a few localized problems which are now slowly being corrected, such as the Duluth-Superior Harbor as well as other Lake harbors, Reserve Mining, etc. The Lake is an excellent example of an oligotrophic lake having very clear, cold water and very few living organisms to decrease light penetration. Suspended solids, which would also affect light penetration, in the open lake average less than 1 ppm and dissolved solids less than 60 ppm. The drawn conclusion from the value of dissolved solids is that the Lake is basically a soft water lake. The low level of nutrients present will affect the types and amounts of organisms that can survive in the water because all algae and plants have certain nutrient requirements. Most dissolved solids are inorganic materials that have leached from the bedrock. Low concentrations of organic materials, primarily from living matter from the tributaries, also enter the Lake.

Oxygen concentration in the Lake remains near saturation values throughout the water column and the entire Lake. These high concentrations exist because of the low amount of organic matter in the sediments as well as in the water.

The slow decomposition of the relatively small quantity of organic matter and the low respiration rate produce only limited amounts of carbon dioxide (CO_2). For this reason the carbon dioxide is at very low concentrations as are bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). The result is that the Lake is poorly buffered (cannot withstand additions of acid or base without changing its acidity or basicity, that is, pH). pH is a means of expressing the acidity or basicity of a sample, with a pH of 7 being neutral. Decreasing pH means increasing acidity. Additions of acid to a weakly buffered system such as Lake Superior can easily change the pH of the system and a drastic altering of water quality can occur.

The table and graph below gives a range of values for various parameters.

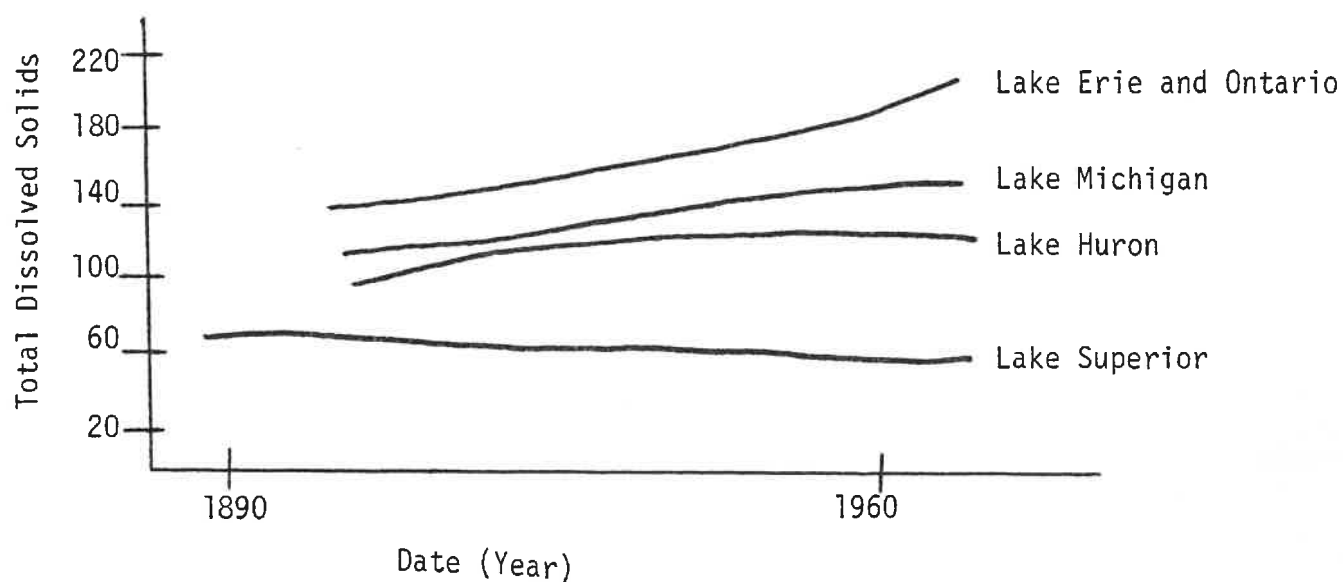
Table I

Water Quality Characteristics of Lake Superior Water

<u>Parameter</u>	<u>Value or Range</u>	<u>Comment</u>
pH	7.2-7.8	Recommended values 6.8-8.5
% Saturation Dissolved Oxygen	90-100%	Amount of oxygen dissolved in water is temperature dependent.
Phosphate (PO_4^{3-})	3-7 ppb	} These are macro-nutrients, when concentrations become very large, then can lead to so called "algal blooms".
Nitrate (NO_3^-)	1-1.2 ppm	
Chloride (Cl^-)	1.2-1.3 ppm	
Iron (fe)	2-83 ppb	EPA Proposed Criteria 300 ppb
Lead (Pb)	<1-8 ppb	EPA Proposed Criteria 30 ppb
Mercury (Hg)	<0.01 ppm	EPA Proposed Criteria 2 ppb
Total Dissolved Solids	~ 60 ppm	Indicates water is basically "soft"

Graph I

Comparison of Total Dissolved Solids in Great Lakes with Time



In the context of environment, the lake is affected by natural occurrences and by people, near or far. Presently studies are being made on the impact of air quality on Lake Superior. Air pollutants such as sulfur and nitrogen oxides, heavy metals, pesticides and PCBs are carried over the lake and settle out or are brought down to the lakes' surface by rainfall. The input of pollutants in this manner may be quite substantial.

BIOLOGICAL CHARACTERISTICS

Water temperature is very important to the cold-blooded organisms which inhabit aquatic systems. Water temperature dictates rates of growth as well as the species which are capable of surviving in the system. The dominant algal group in Lake Superior is the cold water adapted diatoms. Similar temperature restriction is seen in the fish which thrive in Lake Superior. The family Salmonidae, which includes trout, salmon, lake herring, and whitefish, are best able to live in these cold water conditions. Lake trout actually prefer water temperatures of about 50°F. Fish such as largemouth bass, on the other hand, prefer water temperatures of about 80°F and would be hard pressed to grow and survive in Lake Superior.

Although the general statement of low productivity and low abundance of plankton holds true for Lake Superior, local and seasonal fluctuations in plankton populations may result in widely varying numbers. Chequamegon Bay, for example, is a broad, relatively shallow bay in the Apostle Islands area. Phytoplankton and zooplankton populations are generally higher here than in much of the rest of the lake. Similarly, in the southwestern portion, the Superior-Duluth metropolitan area and perhaps red clay erosion contribute more nutrients than are common elsewhere, and plankton populations are relatively high. Comparisons of the number of phytoplankton and zooplankton in the more enriched estuary to that in the lake should generally yield higher counts in the estuary. The complexities of annual temperature changes, life cycles, and the seasonal succession of species, however, sometimes results in numbers which can contradict such expectations.

The complexities involved in monitoring and estimating plankton populations are matched by the history of changes in the status of Lake Superior

fish populations. It might be expected that a group of organisms such as fish would long ago have reached some sort of population equilibrium with its environment. This was probably so a hundred years ago, but the status of fish populations in Lake Superior, and, in fact, all of the Great Lakes, has been in such a state of flux since the early 1900's that it has been almost impossible to predict trends and changes. While many of these changes were initially blamed on over harvest by commercial fishermen, it is now realized that by far the greatest impact has been the accidental or intentional introduction of exotic species of fish. Exotic species are those which did not originally occur in the system. Some have been desirable and no real adverse consequences of the introductions have been realized. Others have been thought desirable and all good intentions backfired. A list of exotic species of fish which are now in the Great Lakes and Lake Superior would include: carp, rainbow trout, brown trout, chinook salmon, coho salmon, rainbow smelt, sea lamprey, and alewife. Some of these are familiar species which it may be surprising to hear are introduced. Others, such as the sea lamprey, have had such severe impacts that they are reasonably well known. A complete discussion of the changes which have transpired due to overfishing and the introduction of the various exotic species is beyond the scope of this paper. An example of one of the better known of the introductions, however, can be used to illustrate some of the unforeseen consequences.

Lake trout and whitefish were the early dominant commercial species in Lake Superior. By 1915, however, lake herring had become the dominant species in terms of total tonnage. That remains true today. At about the same time that lake herring were becoming the dominant Lake Superior commercial species an introduction was taking place in an inland Michigan lake which was to effect all of the Great Lakes. Rainbow smelt were stocked in a lake in 1912 to provide increased forage for predator species. The smelt found their way to Lake Michigan where they established themselves and spread to Lakes Huron, Erie and Superior. Smelt were first found in Lake Superior in 1930. Today they are the single most abundant fish in the lake.

Soon after the smelt became well established in Lake Superior significant decreases in the commercial harvest of lake herring occurred. This was initially blamed entirely on over fishing and many still hold to this belief

today. The coincidental timing of herring declines and smelt abundance, however, and further studies conducted at the University of Wisconsin-Superior indicate that competition and predation by smelt may be the major factor in these declines.

Southwestern Lake Superior was an historically productive area for lake herring. The red clay erosion seems to have been beneficial, possibly by increasing the numbers of zooplankton which is their major food. The primary food of smelt is also zooplankton, although they are effective predators on very small fish.

The occurrence of very definite plumes of turbid water along the coastline allows excellent comparisons of what changes in fish distribution and behavior may occur in clear and turbid water areas. These plumes are often very distinct with a dramatic contrast between the red, turbid water and the clear, blue water. Utilizing a sonic fathometer which shows both water depth and any fish which may occur between the surface and bottom, it is very simple to see the differences in fish distribution as one goes from the clear to the turbid water. In clear water the smelt are distributed very close to the bottom of the lake. In turbid water they occupy positions much closer to the water's surface. It is this simple change in distribution that may have been partially responsible for the decreased abundance of lake herring in the southwestern portion of the lake.

Lake herring spawn on reefs in the lake. When the young hatch they swim to the surface where they remain to feed on zooplankton, especially in the red clay areas. Meanwhile the smelt in these same areas are also feeding on the zooplankton. This creates direct competition for food. The young herring are themselves quite small, and the smelt, which are in the same portion of the water column in the red clay areas, can quite easily consume the young herring as well as the zooplankton. The introduction of this apparently harmless exotic species and the change in distribution due to unique environmental conditions therefore seem to have resulted in the depletion of one of the major Lake Superior resources.

The lake herring-smelt interaction is but one story in a complex saga of daily, seasonal, and man-induced changes that take place in Lake Superior.

This manuscript can only begin to introduce this topic. It has included some general facts and some specific examples, but is intended primarily to acquaint the reader with the area and the general structure of these systems. There are many field and laboratory projects which can be conducted to instruct and clarify some of the specific relationships in these fascinating ecosystems. It is hoped that this brief summary will provide some insights and inspiration for such endeavors.

GEOLOGY OF THE LAKE SUPERIOR REGION

The Lake Superior region constitutes a portion of the southern margin of the Canadian shield of northern North America. The shield is bordered on the south by Paleozoic age rocks and towards the southwest by Cretaceous deposits. Precambrian age rocks (see Geologic time table, Figure 4) constitute the major portion of the western terminus of Lake Superior and have been divided into a number of lithological units some of which contain enormous deposits of iron and copper. The presence of these economically important minerals has, over the years, precipitated an intensive study of the Precambrian though much, as yet, needs to be learned.

The surface or near surface rocks of the major Precambrian age units are shown in Figure 5. The older "basement" sequence, as can be noted from Figure 5, occurs some distance away from the lake shore in Bayfield, Ashland, and Iron counties. These rocks consist of a complex assemblage of slates, quartzites, granites, gneisses and greenstones, dating back to middle and early Precambrian times. These ancient rocks form topographic "highs" in some instances as witnessed by the Penokee-Gogebic Range which extends from the Mellen, Wisconsin area on eastward into Michigan.

The Thomson formation, composed largely of slate and graywacke, outcrops in the northern portion of the study area (see Figure 5) and again is representative of some of the older Precambrian units in the region. A middle Precambrian age has been assigned to the formation and extensive outcrops that can be noted along the St. Louis River in Jay Cooke State Park and immediately below the Thomson dam site.

		MILLIONS OF YEARS AGO	
ERA	PERIOD	EPOCH	
CENOZOIC	Quaternary	Recent Pleistocene	2
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	25 65
MESOZOIC	Cretaceous		135
	Jurassic		190
	Triassic		225
PALEOZOIC	Permian		600
	Pennsylvanian		
	Mississippian		
	Devonian		
	Silurian		
	Ordovician		
	Cambrian		
PRECAMBRIAN	Keweenaw	-Red sandstones, shale, conglomerate -Gabbro (at Duluth & Mellen) -Basaltic lava flows	
	Huronian "Y-Z"	-Slate & graywacke (Virginia, Tyler, Thomson) -Iron formations (Biwabik & Ironwood) -Quartzite (Pokegema, Palms)	
	Algoman	-Granites (Giant's Range, Vermillion)	
	Timiskiming "X"	-Sedimentary Sequence	
	Laurentian	-Granites	
EARLY	Keewatin "W"	-Greenstone, slate, graywacke, iron-formation (Soudan)	

Fig. 4 - Geologic Time-Table

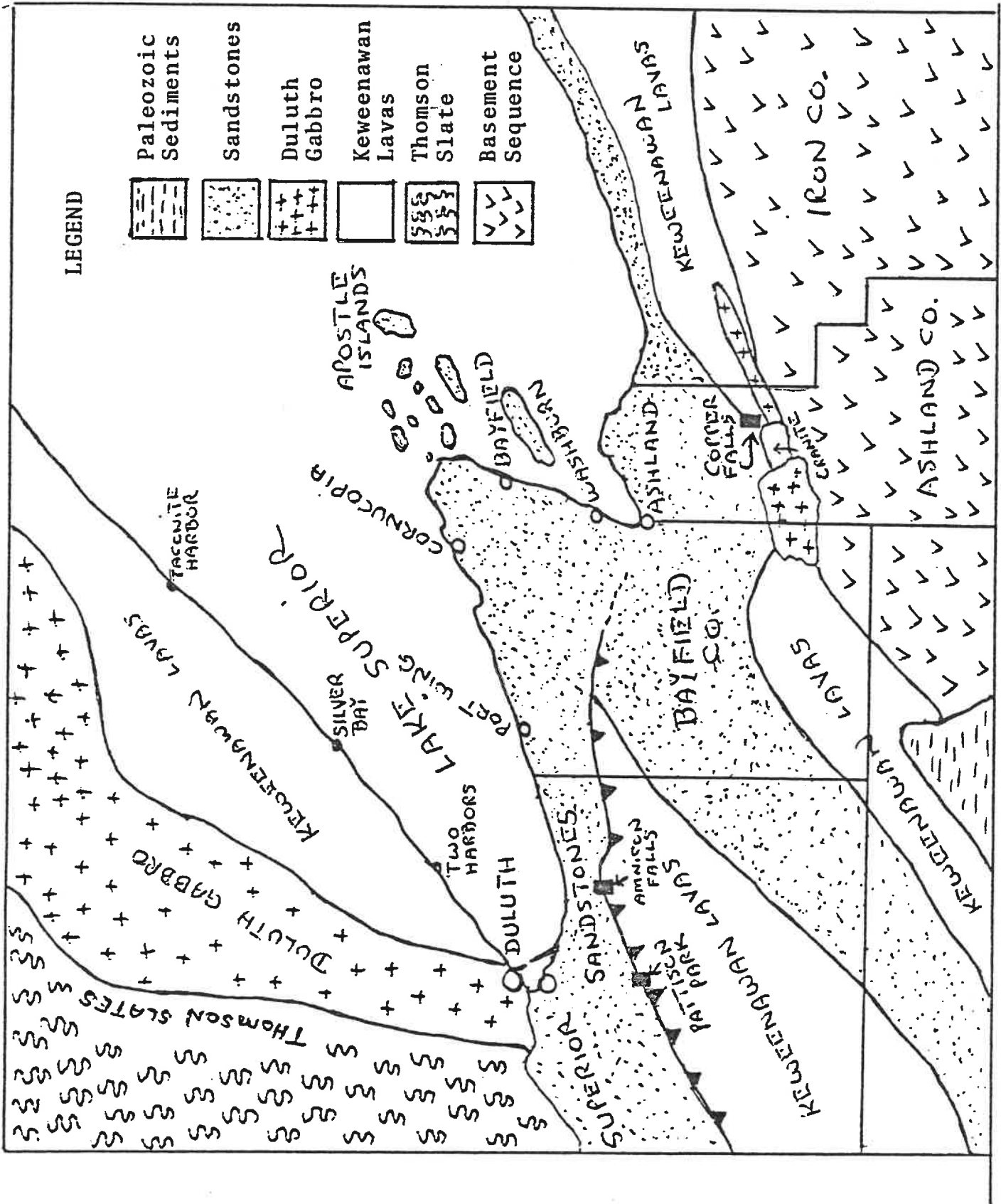


Figure 5. Major Bed Rock Units, Western End, Lake Superior

Field evidence indicates that the bulk of the Thomson formation represents slow accumulation in quiet water and that turbidity currents were initially responsible for transport and deposition of the unit. Subsequent folding and metamorphism took place during the Penokean mountain-building unit some 1.7 billion years ago. Particularly at the Thomson dam site, the student should note the angular relation between foliation (a product of metamorphism) and the original bedding planes (a carry-over from the time when original unit was sediment). Lines of cavities, indicating planes formerly occupied by carbonaceous concretions, are dipping at about the same angle as the original bedding. How does this angle compare to the foliation? Post-folding faults and mafic dikes are well displayed at the site.

Estimates as to the total thickness of the Thomson formation vary from a minimum of 300 feet to a maximum of 20,000 feet.

The reader will note that Keweenaw age lava flows (see Figure 5) constitute much of the north shore of Lake Superior and occur immediately south of the Douglas fault in Douglas County, Wisconsin. Along the north shore, the numerous flows dip gently towards the lake and as many as 140 flows have been counted between Duluth and Two Harbors. Some of the flows have well-developed weathered zones in their upper portions, while others had barely time to cool before they were subsequently covered by younger flows. The wide distribution of the flows (as far south as St. Croix Falls-Taylor's Falls) would suggest that the lava was non-viscous as it originated from deep-seated fissures in the region and spread across the landscape.

Many of the small embayments along the north shore, particularly in the Two Harbors area, are due to instances where the wave action intercepts less resistant weathered zones between the flows. The strike of the flows are not parallel to the shoreline and so intersection of wave action with a non-resistant weathered zone can occur frequently.

The original "home" of Lake Superior agates was in vesicles within the flow units. Subsequent weathering has released them whereupon they were carried into the lake by streams and later washed up onto the beaches by wave activity. The total thickness of the Keweenaw flows is established to be approximately 22,000 feet.

Midway through the Keweenawan, the Duluth gabbro complex was intruded into the above-mentioned lava sequence. Though similar in composition to basalt, gabbro has a coarser-texture, the result of slow-cooling. As noted in Figure 5, the gabbro outcrops in the southwestern part of Duluth. Spirit Mountain, for example, is developed on gabbro which extends as far eastward in Duluth as Mesabi Avenue (vicinity of Radisson Hotel) at which locality it trends inland only to reappear along the shore near Grand Marais, Minnesota (see Figure 5).

Radioactive age determinations indicate the gabbro is about 1.1 billion years old. Its sheet-like character extends, in places, to widths of over 10 miles which may well suggest thicknesses of some thousands of feet. Anorthositic gabbro can be noted in the Enger Tower area and along the north shore beginning at Beaver Bay. At Tofte, Minnesota unusually large masses of anorthosite occur such as at Carlton Peak which is a few hundred feet high and a quarter mile in diameter. Similarly large masses occur northward between Tofte and Grand Marais forming very discernable knobs on the skyline. The aluminum content of feldspar-rich anorthosite has attracted commercial interest to the region in the past.

It is evident from the map (Figure 5) that much of the south shore of the lake including the Apostle Islands is underlain by the Lake Superior Sandstone. This unusually thick unit (22,000 feet) is divided into the younger, flat-lying Bayfield Group and an older, highly deformed Oronto Group which outcrops in areas south and east of Ashland. The Bayfield Group made up of the Chequamegon, Devils Island, and Orienta formations is separated from the Oronto Group by an angular unconformity and is exposed at well-known tourist attractions such as Pattison State Park, Amnicon Falls State Park, and the Apostle Islands. In particular, the Orienta Formation is represented at Pattison Park and Amnicon Falls while the Chequamegon makes up the bulk of the Bayfield peninsula and the Apostle Islands. The soft friable Devils Island sandstone gives rise to numerous sea-caves along the shore in the vicinity of Cornucopia and also on Devils Island in the Apostles.

The Lake Superior sandstone is entirely of fluvial origin and represents a thick accumulation of sediment into an extensive basin. Lake Superior, as we now know it, was not present at the time. The older basement rocks, however,

were deformed into an extensive depression or syncline which accommodated thick river laid deposits representing weathered debris from older units. A complete lack of fossils in the sandstones reflects either the limited amount of life present during late Precambrian time or, most likely, severe oxidation which destroyed any organic remains trapped in the sands.

Following the deposition and lithification of the Lake Superior sandstone, a prolonged period of weathering and erosion characterized the region. It is possible that some of the Paleozoic sedimentary formations now commonplace in the central and southern portions of the state may well have covered the Lake Superior area. If so, all evidence has been removed.

Commencing two million years ago, the first of four ice advances covered the Lake Superior region and advanced southward as far as the Ohio River. A well-developed stream occupying the area now covered by Lake Superior was gouged to some depth by a lobe of the southward flowing ice. Subsequent advances of the ice continued the deepening process and was of sufficient thickness to over-ride the Duluth hills and leave tell-tale grooves and striations on exposed bedrock surfaces. Considerable amounts of pulverized basalt, gabbro, and sandstone were carried further south by the ice, and now provide fertile soils for farms in the southern reaches of the state.

When the last ice mass (Wisconsin glacier) began a slow retreat 10,000 years ago, from the Twin Ports area, water was impounded in the lake basin between the ice front and the highlands surrounding the western tip, of the lake. The eastern drainage outlet was blocked by ice and a large lake known as glacial Lake Duluth came into existence. The water stood at elevations from 500-600 feet above the present lake level which is 602 feet above sea level. All of Superior and a considerable portion of Duluth was under water at this time. Currently the skyline drive in Duluth follows one of the highest shorelines developed at this time. Wave cut cliffs and terraces are prominent along many parts of the drive. At this time, rivers draining into the large lake from a subdued hinterland deposited a layer of red clay which today forms the level plain on which the cities of Superior and Ashland are built. For a prolonged period of time, the outlet for this large glacial lake Duluth was through the Brule River valley into Lake St. Croix at Solon Springs and thence through the St. Croix River valley to the Mississippi River. To

this day, as one approaches the Brule valley from the east or the west, he notes the unusual width of the valley compared to the small size of the Brule channel. At times past, the entire valley was filled with a torrential flow of water towards the south during which time the large valley was carved.

With continued retreat of the ice to the north, the eastern outlet of the Great Lakes was established and the level of Lake Superior declined. Several intermediate beach lines were established one of which serves as the base on which UMD is constructed. Continued depression of the lake level resulted in a low stage some one hundred feet below the present level of the lake. Streams draining into the lower level of the lake dissected the red clay deposits into V-shaped youthful valleys. Approximately 5000 years ago, the lake level slowly rose to an elevation of 607 feet and subsequently slowly declined to its present level of 602 feet. The rise of lake level from its low point, as mentioned above, flooded many of the youthful V-shaped valleys which had developed at the low stage and created the numerous peninsulas and points of land which characterize St. Louis Bay.

In areas removed from the lake, "swell and swale" topography typical of ground moraine as well as "knob and kettle" topography associated with terminal moraine gave rise to depressions which subsequently filled with water giving rise to the vast majority of Minnesota's 10,000 lakes and Wisconsin's 8600 lake basins. Obviously the effects of the glacial ages had a remarkable influence in dictating the current nature and use of the landscapes.

EXPERIMENTAL DETERMINATION OF OXYGEN IN WATER

General Considerations

The amount of oxygen gas (O_2) dissolved in natural waters is probably the most important consideration relating to the quality of the water. The dissolved oxygen gas is essential to the following processes:

1. Respiration and Decomposition of Aquatic Plants and Animals

Animals will take up oxygen and eliminate carbon dioxide during respiration. When aquatic plant material dies, it is broken down by bacterial action and converted to simpler products such as carbon dioxide. Oxygen is consumed

in this process. If sufficient oxygen is not present in the water, most forms of aquatic life cannot exist. In the absence of oxygen, decaying plants and animals will be converted to more toxic substances such as methane gas (called swamp gas), hydrogen sulfide gas (smells like rotten eggs) and phosphine gas (also has a strong odor).

When certain pollutants, such as most organic wastes, are added to water, bacteria begins breaking down the waste material thus consuming oxygen in the process. If the amount of waste is sufficient, the water may become depleted of oxygen gas or lowered to a level insufficient to support fish and other aquatic like. Many fish kills have resulted by the consumption of oxygen by wastes.

2. Photosynthesis

Oxygen is produced in water (and in air) by the process of photosynthesis. Green plants (containing chlorophyll) will take up carbon dioxide and water, and in a series of chemical reactions, convert these reactants to O_2 gas and sugars. Some oxygen will dissolve in water from the air. These two processes (photosynthesis and air-exchange) are the only methods by which water can obtain its oxygen content. However many processes consume oxygen as illustrated under the Respiration section.

For a lake to have a good supply of oxygen, sufficient green plant life (such as aquatic weeds, algae and phytoplankton) must be present. However, if excess amounts of aquatic plant life exist, such as in swampy areas and lakes with high algae concentrations, the decay of these plants may reduce the amount of oxygen to very low levels.

Light penetration is another important consideration toward oxygen content. For photosynthesis to occur, sunlight is necessary. Thus if waters are clear, sunlight will penetrate to great depths allowing the production of O_2 down to a relatively great depth. Some lakes may be oxygen deficient near the bottom (hypolimnion) because of the absence of light penetration to the bottom of the lake.

2. Oxidation-Reduction Chemical Processes

Many chemical species exist in a natural water system ranging from simpler dissolved chemical elemental species (such as forms of nitrogen, phosphorus and metals) to complex organic molecules. The presence of oxygen in water is

necessary for most chemical reactions called oxidation reactions to occur. In contrast, when oxygen levels are low to absent, reduction chemical reactions tend to be dominant.

When plant and animal forms decompose in water, much more desirable products result when decomposition occurs under oxidizing (high O_2 in water) conditions than in the case of reducing (low to absent O_2 in water) conditions. Toxic substances are produced under reducing conditions.

An example of an adverse effect of the presence of reducing conditions is the possible release of toxicants from bottom sediments. Under reducing conditions chemical transformations can occur in the sediments which can result in the release of toxicants such as heavy metals.

In general the chemical species present in water are in much more desirable forms when oxidizing conditions exist in the body of water.

4. Solubility of Minerals

Minerals are flushed into bodies of water due to land drainage. For example, the Nemadji River transports large quantities of red clay particles into the Superior harbor and ultimately Lake Superior.

The speed at which the minerals dissolve in water and the products formed depend upon oxygen levels (oxidizing or reducing conditions) among other factors. The dissolving process adds to the water silica (SiO_2), calcium (Ca), magnesium (Mg), sodium (Na), carbonate (CO_3) and bicarbonate (HCO_3) in addition to other chemical species. These chemicals provide foods for plant life. They also contribute to the hardness of the water and its ability to resist the effects of acid rain.

Solubility of Oxygen in Water

Oxygen gas is not very soluble in water. Aquatic plant and animal life have evolved in order to exist at the much lower oxygen levels found in water than found in the air. Also the amount of oxygen gas which can be dissolved in water varies according to water conditions. One important factor is temperature. Oxygen gas is more soluble in cold water than warm water.

When the water dissolves as much oxygen gas as it can, the water is said to be saturated in oxygen. A cold trout stream near sea level will contain much more oxygen at saturation than a warm salty pool. Because trout need

higher amounts of oxygen in the water than cat fish, trout tend to only exist in cold water systems where the oxygen levels are high enough for their requirements. Catfish may be able to exist in either cold or warm water systems.

Much of the aquatic life requires near saturation levels of oxygen in the water. Some of these saturation amounts are given below for different water temperatures.

<u>Temperature ($^{\circ}\text{C}$)</u>	<u>ppm of O_2 at Saturation</u>
0	14
10	11
20	9
30	7.5

The saturation values are listed in parts of oxygen per million parts of water. For example, at 0°C , one million pounds of saturated water (or 123,000 gallons) would contain 14 pounds of oxygen gas or one ounce of oxygen gas would be contained in 550 gallons of water.

Measurement of Dissolved Oxygen

Two common methods of measuring oxygen gas in water are the Winkler titration technique and the dissolved oxygen meter employing an electronic probe. The Winkler method is relatively accurate but requires a number of chemicals and laboratory glassware. Use of a dissolved oxygen meter is the most rapid method but the instrument is expensive.

1. Winkler Titration: Azide Modification

- A. Collect the water in a sampler designed to prevent contact with the air. Measure the water temperature. Run the sample into a 300 ml BOD bottle allowing the water to overflow.
- B. Using dropper bottles or pipets, add the following to the sample below the water surface:
 - 1) 2 ml of manganous sulfate solution
 - 2) 2 ml of alkali-iodide-azide reagent

- C. Stopper the bottle being careful to exclude any air bubbles and shake for two minutes. A yellow fluffy solid (precipitate) will form. Allow the precipitate to settle to near the bottom. Then reshake briefly and again allow the precipitate to settle.
 - D. Add 2 ml of concentrated sulfuric acid, restopper and shake. The precipitate should dissolve.
 - E. Measure 200 ml of the sample into a 500 ml Erlenmeyer flask.
 - F. Fill a buret with 0.025 N thiosulfate (or phenylarsine oxide) solution and record the level of the thiosulfate solution in the buret. Titrate the sample in the flask with the thiosulfate solution until the sample is a pale straw color.
 - G. Add 1-2 ml of starch solution and the sample will turn blue. Continue to add the thiosulfate solution until the blue color disappears. Record the level of the thiosulfate solution in the buret. Calculate the volume added.
 - H. The number of milliliters of thiosulfate solution equals the ppm's of dissolved oxygen in the water sample.
2. The use of a dissolved oxygen meter is ideal for making measurements from a boat in the field. A probe containing a membrane can be lowered to various water depths and the amount of dissolved oxygen can be read directly from a meter. The instrument must be calibrated frequently to insure correct readings. Specific operating instructions are provided with the instrument.

APPENDIX A

SOME COMMON AND AVERAGE VALUES FOR LAKE SUPERIOR *

MORPHOLOGY:

Volume	12,000 ± 200 km ³
Max depth	405 m
Area of basin	210,000 km ²
Area of lake	82,000 km ²
% Forest cover, land	95%
% Winter ice cover	40-95%

OPTICAL PROPERTIES:

Open water	always < 1 JTU; typically < 0.5 JTU
	Secchi depth 9-15 m.
Nearshore	Secchi depth 5-11 m.
	1.5-2.8 m (minimum)

Vertical extinction coefficient	0.15-0.25 m ⁻¹ (400-500 nm)
Mean depth of photic zone	20-30 m.

Sediments:

Sedimentation rate:	0.1-2.0 mm/year
	6 x 10 ⁶ tonnes/yr of fine sediment in Lake Superior

CHEMISTRY:

Average concentration of major ion filtered (0.45 m)

Ca ⁺²	12.9 mg/L	0.644 meq/L	Ionic strength = 1.09 mM
Mg ⁺²	2.8	0.230	
Na ⁺	1.2	0.052	
K ⁺	0.5	0.013	
SO ₄ ⁻²	3.2	0.067	
Cl ⁻	1.2	0.034	
Alkalinity (CaCO ₃)	41.9	0.838	

Specific conductance (25°C)	97 μS/cm
pH	7.9-8.3

Average concentration of trace metals filtered (0.45 μm)

Cd	0.1 μg/L	0.009 μM
Co	0.2	0.003
Cr	0.1	0.002
Cu	2.3	0.036
Fe	2.1	0.038
Hg	0.1 (unfiltered)	0.0005
Li	0.8	0.1
Mn	0.4	0.007
Mo	0.2	0.002
Ni	1.6	0.027
Pb	0.8	0.003
Sr	29	0.33
Zn	1.8	0.028

PHYSICAL

Average precipitation:	75.2 cm/yr
on Lake	61.7 km ³ /yr
Range of maximum lake surface temp	11-16°C
Evaporation from lake: 50%	30.8 km ³ /yr
Average net input to lake from rivers and diversions	48.9 km ³ /yr
Average net outflow (St. Mary's River) range (63.1-82.3 km ³ /yr)	69.7 km ³ /yr
Residence time (re input)	108 ± 10 yr
(re outflow)	172 ± 10 yr

Major tributaries in decreasing order:

Nipigon R., St. Louis R., Montreal R., Michipicoten R., Kaministikwia R., Long Lac, Ogoki, Magpie R., White R.

Global radiation	76 (Dec.) to 544 (July) cal/cm ² /day
Net radiation	-111 (Dec.) to 420 (July) cal/cm ² /day
Latent heat	201 (Dec.) to -25 (June) cal/cm ² /day
Sensible heat	-122 (May) to 247 (Dec.) cal/cm ² /day
Annual heat budget	65,000 cal. cm ⁻²

Average concentration of nutrients

NO ₃ ⁻ -N	300 μg/L	21 μM
NH ₄ ⁺ -N	2-6	0.1-0.4
SiO ₂	2400	40
Total P	3-6	0.1-0.2
Soluble reactive P	0.5-1.5	0.02-0.05

Precipitation chemistry

Ca	0.59-0.72 mg/L	0.015-0.018 mM
Mg	0.17	0.0070
Na	0.33-0.68	0.014-0.030
K	0.18-0.26	0.0046-0.0067
SO ₄	2.7-3.8	0.028-0.040
Cl	0.95-1.3	0.027-0.037
Alkalinity	0.2-8.3	0.004-0.166
SiO ₂	0.05-0.11	0.0008-0.0018

BIOLOGY:

Primary Production	Phytoplankton Biomass	Chlorophyll <i>a</i>
(mg/m ³ /hr.)	(mg/m ³)	(mg/m ³)
0.5-35	0.02-0.27	0.4-3.8

Nannoplankton (< 64 μm) = 57-80% of biomass and represent 87-94% of primary production.

Major algal groups - Chrysomonads, Cryptomonads, Diatoms
Crustacean Zooplankton

	Lakewide average
	Numbers
Seasonal range	200-500/m ³
	Biomass
	5-.25 mg/m ³

Major groups-Calanoids, Cyclopoids, Cladocerans

Macrobenthos	Lakewide mean
	Numbers
	525/m ²
	Biomass
	50 mg/m ²

Dominant forms *Pontoporeia* (Amphipoda)

Mysis relicta (Decapoda) - partly planktonic

* Journal of Great Lakes Research, Volume 4, Number 3-4, 1978.

APPENDIX B

KEY TO LAKE SUPERIOR ZOOPLANKTON

This key allows identification of the common organisms that will be collected from the open water of Lake Superior by use of plankton nets and water bottles. Most benthic organisms and some littoral species are not included.

This key is designed for introductory work only and is adapted from Taxonomic Keys to the Common Animals of the North Central States by S. Eddy and A.C. Hodson. For more advanced work and identification to the species level the following works should be consulted:

H.B. Ward and G.C. Whipple. 1959. Freshwater Biology, ed. W. T. Edmondson John Wiley and Sons. New York.

Grothe, D.W. and D.R. Grothe. 1977. Illustrated Key to the Planktonic Rotifers of the Laurentian Great Lakes. U.S. EPA. Region V. Chicago, Ill.

Czaika, S.C. and A. Robertson. 1968. Identification of copepodids of the Great Lakes species of Diaptomus. Proc. of Conf. on Great Lakes Res. 11:39-60.

Brooks, J.L. 1959. The Systematics of North American Daphnia. Memoirs of the Connecticut Academy of Arts and Sciences. Yale University Press.

GLOSSARY OF TERMS

Abdomen - the most posterior of the major body divisions

Anterior margin - the front edge of body

Antennae - the first appendages of the body. Crustacea have two pair of antennae, the first pair usually being quite small with the second pair much larger.

Biramose - having two branches. Refers to crustacean appendages with two branches.

Bivalve - a shell-like covering consisting of two equal halves

Carapace - the shell covering a portion or all of the cephalothorax

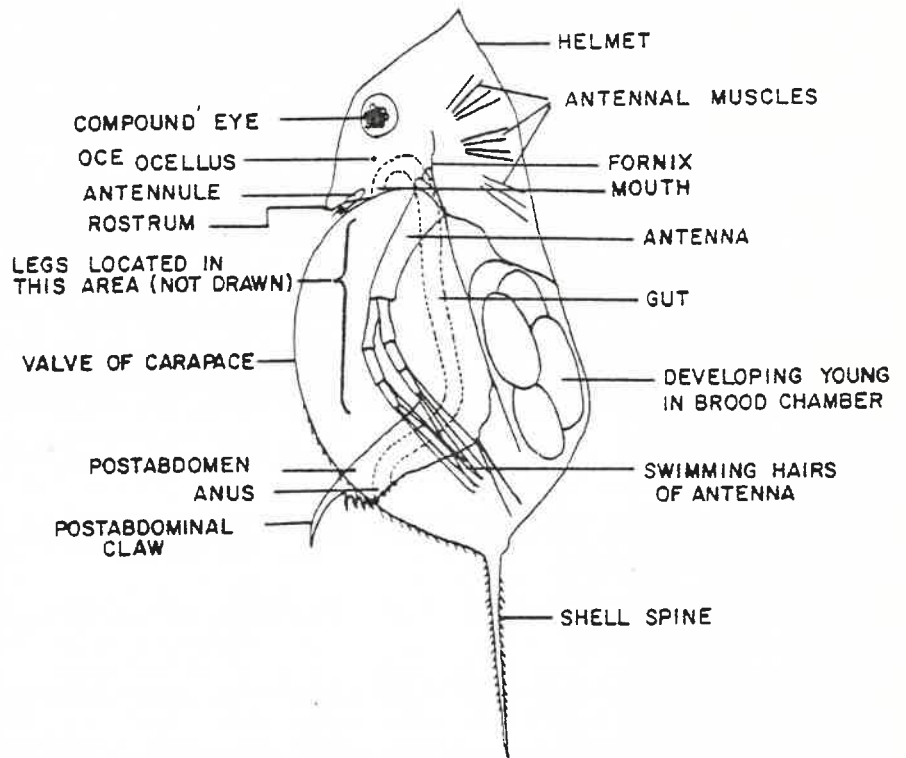
Caudal - located at the hind portion of the body

Cephalothorax - a major body division formed by the fusion of the head and thorax

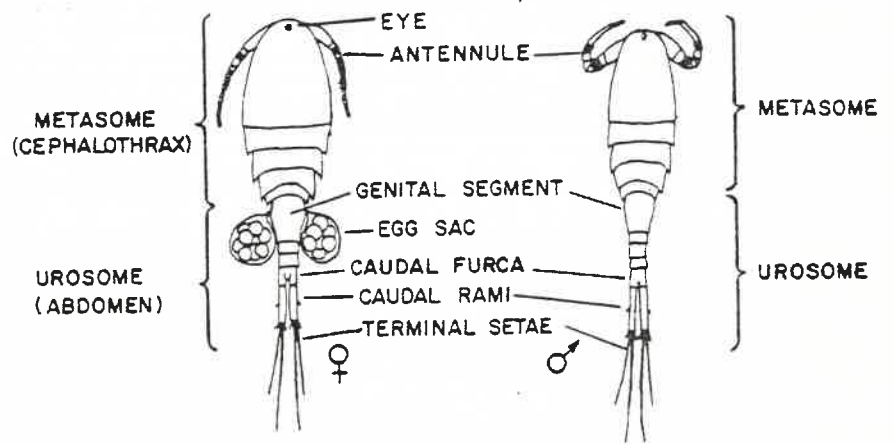
Cilia - fine, hairlike structures

- Lorica - hardened cuticula forming a shell-like rigid surface covering which is often ornamented with spines and other projections
- Nauplius - a larval form of many of the crustaceans
- Ocellus - a minute simple eye or eyespot
- Pecten - larger spines, particularly those at the base of the post-abdominal claw
- Pleopods - abdominal appendages of higher crustacea
- Post-abdominal claws - a pair of claw-like structures at the tip of the post-abdomen of cladocerans
- Ramus, Rami - branches of a typical unmodified paired appendage, forms the large branches of the antennae of cladocera
- Rostrum - beak-like structure projecting forward or downward from the head
- Setae - bristle-like structures
- Thorax - part of body between head and abdomen
- Truncate - cut off abruptly to form a square edge or tip

General Morphology of a Cladoceran



General Morphology of the Copepoda



LAKE SUPERIOR ZOOPLANKTON

Key A: Major taxonomic groups

- 1) Animals with backbones or notochords - - - - - Phylum Chordata
 (Fish larvae - not keyed)
 Animals without backbones - - - - - 2
- 2) Minute animals with rings of cilia on anterior margin,
 Internal jawlike structures present anteriorly - - - - Phylum Rotatoria
 (wheel animals - see Key B ... Figures 1-14)
 Larger animals without rings of cilia, body segmented
 with paired appendages - - - - - Phylum Arthropoda - 3
- 3) Two pair of antennae (2nd pair harder to see) -
 biramous appendages - - - - - Class Crustacea - 5
 Less than two pair of antennae - - - - - 4
- 4) No antennae, 4 pair walking legs - - - - - Class Arachnida
 (mites, spiders . . . Figure 15 . . . not keyed)
 One pair antennae, body usually divided into head,
 thorax, abdomen - - - - - Class Insecta
 (insect larvae, Figures 16-17...See also
 Appendix C)
- 5) Body of 20 segments, Thorax with 7-8 pair appendages,
 abdomen with 6 pair - only last segment without
 appendages - - - - - Subclass Malacostraca
 (Figures 21-25. . . See Key C)
 Variable number of body segments, last few without
 paired appendages - - - - - 6
- 6) Trunk appendages flattened and leaf-like - - - - - Subclass Branchiopoda -
 (Figures 18-20 and 28-40) 7
 Trunk appendages slender, jointed and used for
 walking or swimming - - - - - 8
- 7) Ten or more pair of trunk appendages . . . not keyed -
 Not common in Lake Superior
Order Anostraca - Fairy Shrimp - Fig. 19
Order Notostraca - Tadpole Shrimp - Fig. 18
Order Conchostraca - Clam Shrimp - Fig. 20
 Four to 6 pair trunk appendages - most have bivalve
 carapace and large biramous antennae - - - - - Order Cladocera
 (water fleas . . . see Key D . . . Fig. 28-40)
- 8) Two pair trunk appendages, body covered by bivalve
 carapace - - - - - Subclass Ostracoda
 (seed shrimp, Figures 26-27, not keyed)
 Four to 5 pair biramous-trunk appendages, body not
 covered by carapace - - - - - Subclass Copepoda
 (copepods, Figures 41-47, See Key E)

Key B: Rotifers - Genus Key

- 1) Lorica present, forms a stiff, shell-like case - - - - 2
Lorica absent - 8
- 2) With foot or toes - - - - - - - - - - - - - - - - - 3
No foot or toes - - - - - - - - - - - - - - - - - - - 7
- 3) Foot extends from middle of ventral surface of wrinkled lorica, Fig. 1 - - - - - - - - - - - - - - Pleosoma
Foot extends from posterior margin of lorica - - - - - 4
- 4) Lorica cylindrical, foot reduced, 1 or 2 bristle-like toes . . . Fig. 2 - - - - - - - - - - - - - - - - - Trichocorca
Foot well developed, lorica not cylindrical - - - - - 5
- 5) Foot short, 1 or 2 elongate toes - - - - - - - - - - 6
Foot elongate - 2 short toes . . . Fig. 3 (lorica only shown) - - - - - - - - - - - - - - - - - Brachionus
- 6) Long single toe . . . Fig. 8 - - - - - - - - - - - - Monostyla
Long paired toes . . . Fig. 9 - - - - - - - - - - - - Lecane
- 7) Anterior spines on lorica equal in length, 1 or 2 posterior spines, lorica has plate-like structures . . . Figures 5-6 - - - - - - - - - - - - - - Keratella
One or more anterior spines greatly elongated, long posterior spine . . . Figure 11 - - - - - - - - - - - - Kellicottia
- 8) No foot or toes - - - - - - - - - - - - - - - - - - 9
Foot or toes present - - - - - - - - - - - - - - - - - 12
- 9) Large sac-like body - no lateral appendages . . .Fig. 4 Asplanchna
Lateral appendages present - - - - - - - - - - - - - 10
- 10) Two long filamentous lateral appendages and 1 posterior filament that are longer than the body . . . Fig. 13 Filinia
Appendages shorter than body - - - - - - - - - - - - 11
- 11) Appendages paddle-like . . . Fig. 7 - - - - - - - - - Polyarthra
Six arm like appendages ending in setae . . . Fig. 10 Hexarthra
- 12) Body tapers to a short foot with 2 toes, anterior ciliated lobes present, foot often retracts when preserved . . . Fig. 14 - - - - - - - - - - - - - - Synchaeta
Long stem-like foot, no toes, gelatinous tube, colonial . . . Fig. 12 - - - - - - - - - - - - - - Conochilus

Key C: Subclass Malacostraca

- 1) No carapace - eyes not stalked - - - - - 3
 Carapace covers first 3 thorax segments, eyes stalked 2
- 2) Last 5 pair thoracic legs long and thin, pleopods small
 . . . Fig. 21 . . . Order Mysidacea Opossum shrimp - Mysis relicta
 Pleopods well developed . . . (Crayfish - not keyed)
 . . . Fig. 22 - - - - - Order Decapoda
- 3) Body compressed laterally - (Scuds, not keyed) . . .
 Fig. 23-24 - - - - - Order Amphipoda
 Body flattened dorsal-ventrally (sowbugs - not
 keyed) . . . Fig. 25 - - - - - Order Isopoda

Key D: Order Cladocera

- 1) Body and feet enclosed in a bivalve shell, feet
 flat, not distinctly jointed - - - - - 3
 Body not completely enclosed in a carapace - feet
 jointed 2
- 2) Abdomen short, caudal process long and slender, 2
 long caudal setae . . . Fig. 28 - - - - - Polyphemus pediculus
 Abdomen long and slender, terminates in 2 stout processes
 Animal 10-20 mm . . . Fig. 31 - - - - - Leptodora kindtii
- 3) Valves gelatinous and humped. Second antennae not
 branched . . . Fig. 32 - - - - - Holopedium
 Valves not gelatinous, second antennae with 2
 branches - - - - - 4
- 4) Second antennae large - basal segment 1/3 body length.
 Row of numerous setae on larger branch of antennae - 5
 Basal segment of second antennae less than 1/4 body
 length. No setae in row - - - - - 6
- 5) Lateral extension on basal segment of dorsal branch
 of second antennae . . . Fig. 29-30 - - - - - Latona
 No lateral extension on dorsal branch . . . Fig. 33 Diaphanosoma
- 6) First antennae attached to side of head, covered by
 projections which form a beak. Second antennae has
 2 segments in each branch - - - - - 7
 First antennae attached to ventral surface of head.
 No 'beak'. More than two segments to branches of
 second antennae - - - - - 8
- 7) Valves spherical, ventral margin rounded . . . Fig. 34 Chydorus
 Valves oval, ventral margin straight, lateral
 clusters of spines on post-abdomen . . . Fig. 35 - Leydigea

- 8) Rostrum well developed . . . Daphnia sp. - - - - - 9
- Rostrum not developed - - - - - 10
- 9) Ocellus present, fine pecten on postabdominal
claw . . . Fig. 36 D. galeata mendotae
- Ocellus absent, coarse pecten on claw, helmet
curved . . . Fig. 39 - - - - - D. retrocurva
- 10) First antennae elongate. Forms immovable 'tusk' - - 11
- First antennae truncate, head small . . . Fig. 37 - Ceriodaphnia
- 11) Tail-like structure present . . . Fig. 40 - - - - - Bosmina longirostris
- No tail-like structure . . . Fig. 38 - - - - - Eubosmina coregoni

Key E: Subclass Copepoda

Key to adult animals only.

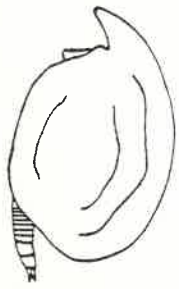
Nauplii stage resembles Figure 48.

Copepodid stages resemble adults but do not have fully developed appendages and are harder to key.

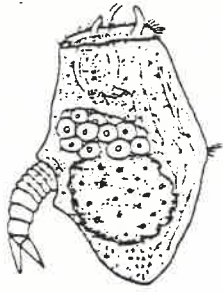
For our use: Adult females are carrying eggs.
Adult males have geniculate (bent) antennae.

- 1) Anterior part of body broader than posterior - - - 2
- Anterior part of body same width as posterior (Fig. 41-
not keyed) - - - - - Order Harpacticoida
- 2) First antennae of 23-26 segments as long as abdomen Order Calanoida - 3
- First antennae of less than 17 segments, shorter
than body - - - - - Order Cyclopoida - 6
- 3) Caudal rami long - at least 3 times width - - - 5
- Rami shorter - - - - - 4
- 4) Three well developed broad caudal setae, abdomen
asymmetrical . . . Fig. 47 - - - - - Epischura lacustris
- Five short Filamentous caudal setae . . . Fig. 46 - Diaptomus
- 5) Rami 3 times width, animals 1 to 1.5 mm . . Fig. 45 Eurytemora affinis
- Rami 5 times width, large animals 2 to 3 mm . Fig. 44 Limnocalanus macrorus
- 6) Caudal rami short, hairs on inner margin -
- rami forked (人) . . . Fig. 42 - - - - - Mesocyclopsedax
- Caudal rami longer, no hairs on inner margin,
rami straighter (人) . . . Fig. 43 - - - - - Cyclops

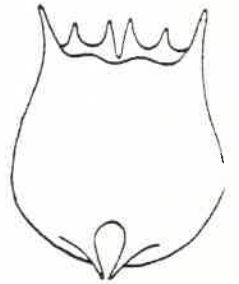
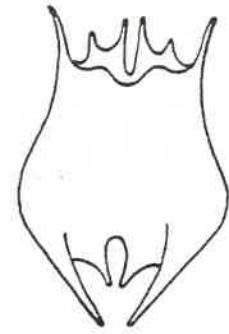
ROTIFERS



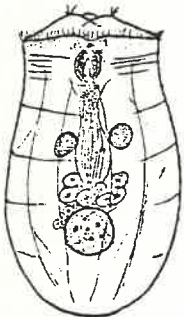
1 Ploesoma sp.



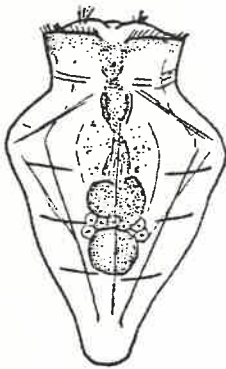
2 Trichocera spp.



3 Brachionus furcullatus



4 Asplanchna sp.

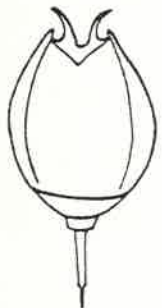


5 Keratella cochlearis

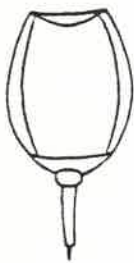
6 Keratella quadrata



7 Polyarthra trigla



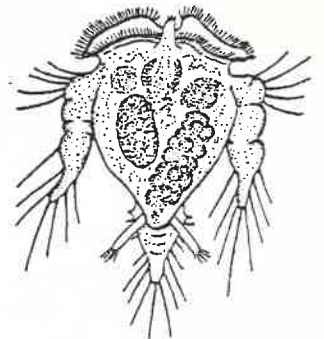
8 Monostyla spp.



9 Lecane spp.



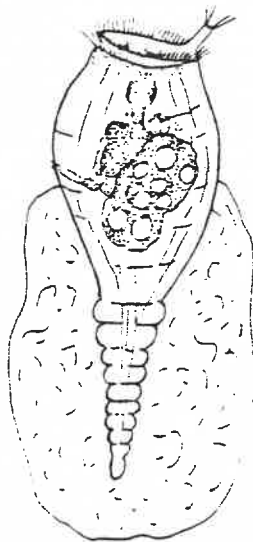
13 Filinia longiseta



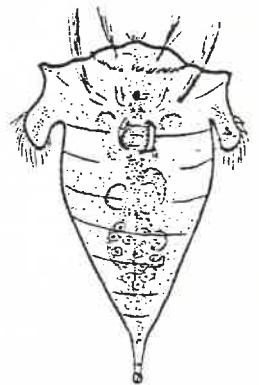
10 Hexarthra mira



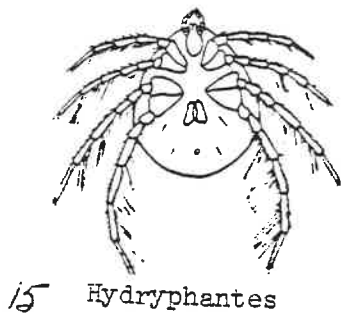
11 Mellicottia longispina



12 Conochilus sp.



14 Synchaeta sp.



15 Hydryphantes

MITES

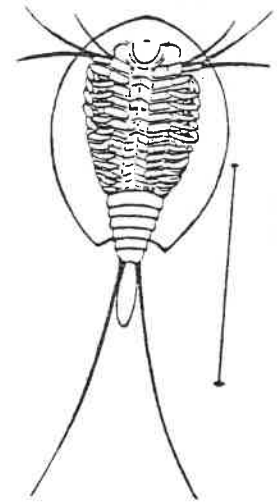


16 Diptera
Genus Tendipes

INSECTS



17 Diptera
Genus Chaoborus



♂ Lepidurus couesi

TADPOLE SHRIMP

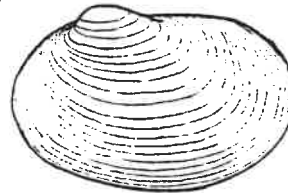


Chirocephalopsis bundyi, female

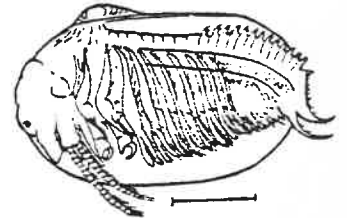


19 Chirocephalopsis bundyi, male

FAIRY SHRIMP

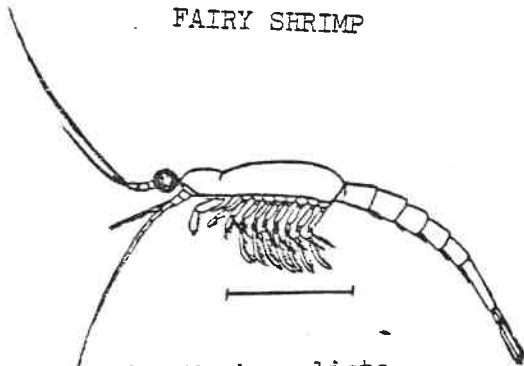


Cyzicus mexicanus,
left valve

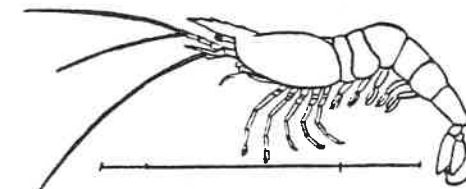


Cyzicus mexicanus,
left valve removed

CLAM SHRIMP

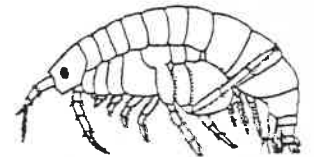


21 Mysis relicta

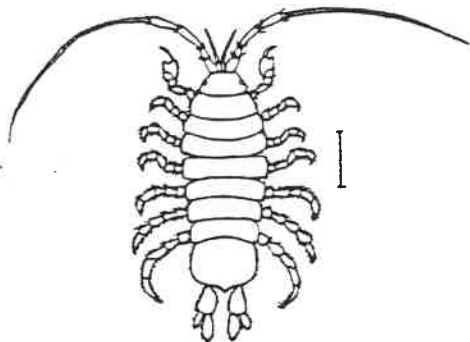


22 Palaemonetes exilipes

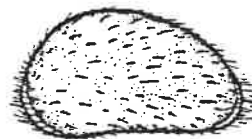
MALACOSTRACA



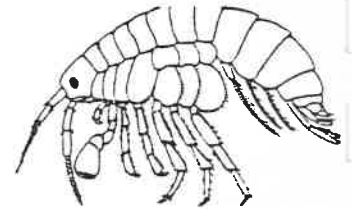
23 Pontoporeia affinis



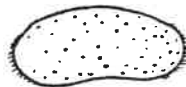
25 Aquatis isopod, Asellus sp.



26 Pomatocypris sp.



24 Hyalella azteca



27 Candona simpsoni

OSTRACODS

CLADOCERANS



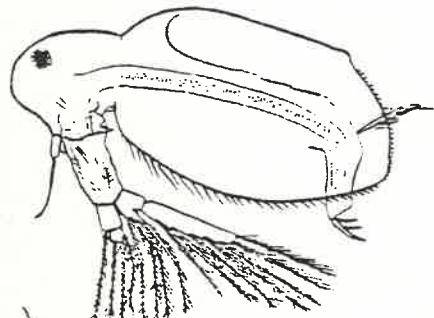
28 Polyphemus pediculus



31 Leptodora kindtii



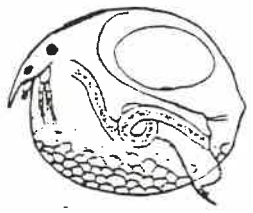
32 Holopedium gibberum



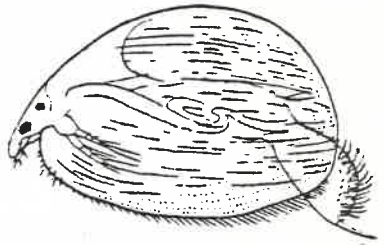
29 Latona parviremus



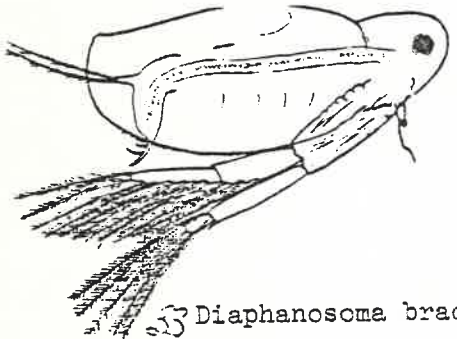
30 Latona setifera (antenna)



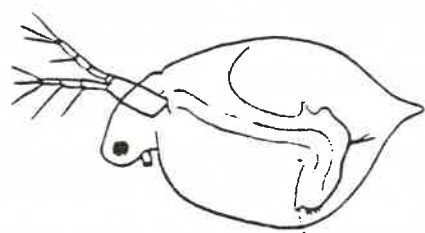
34 Chydorus sphaericus



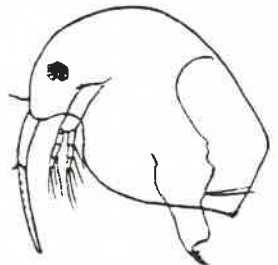
35 Leydigia acanthocercoides



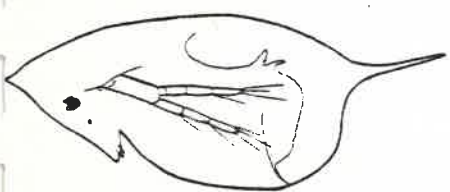
33 Diaphanosoma brachyurum



37 Ceriodaphnia lacustris



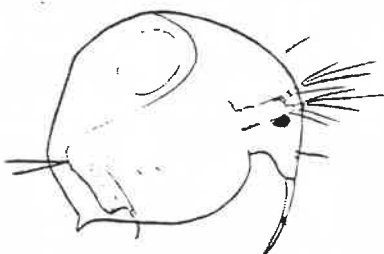
38 Bosmina coregoni



36 Daphnia galeata

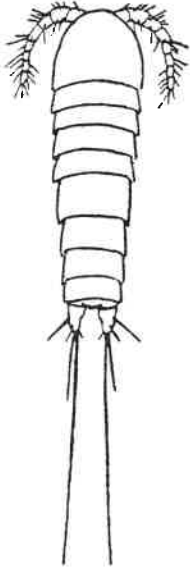


39 Daphnia retrocurva

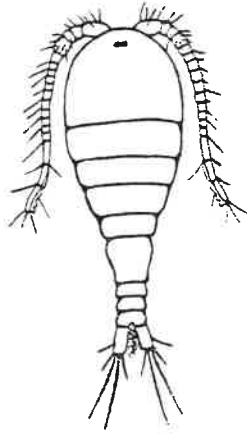


40 Bosmina longirostris

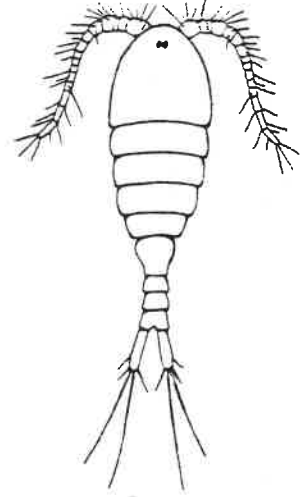
COPEPODS



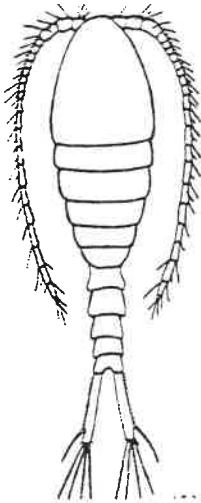
41 Canthocamptus sp.



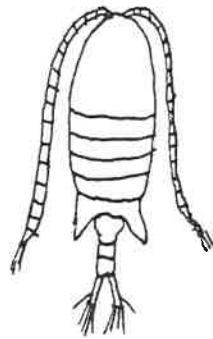
42 Mesocyclops edax



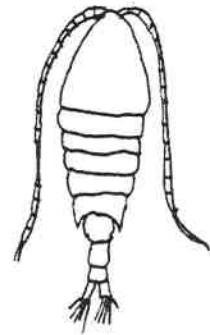
43 Cyclops vernalis



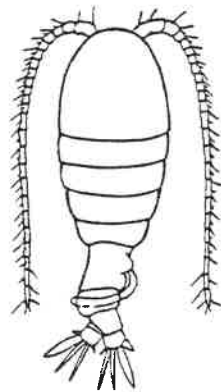
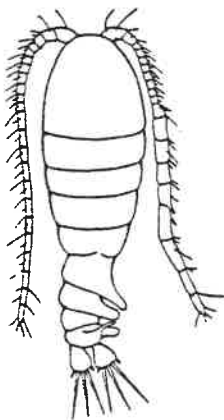
44 Limnocalanus macrurus



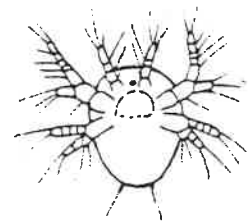
45 Eurytemora affinis



46 Diaptomus sp.



47 Epischura lacustris, male and female



48 Nauplius stage

APPENDIX C

Key to Orders of Insects (from Hilsenhoff, 1975)

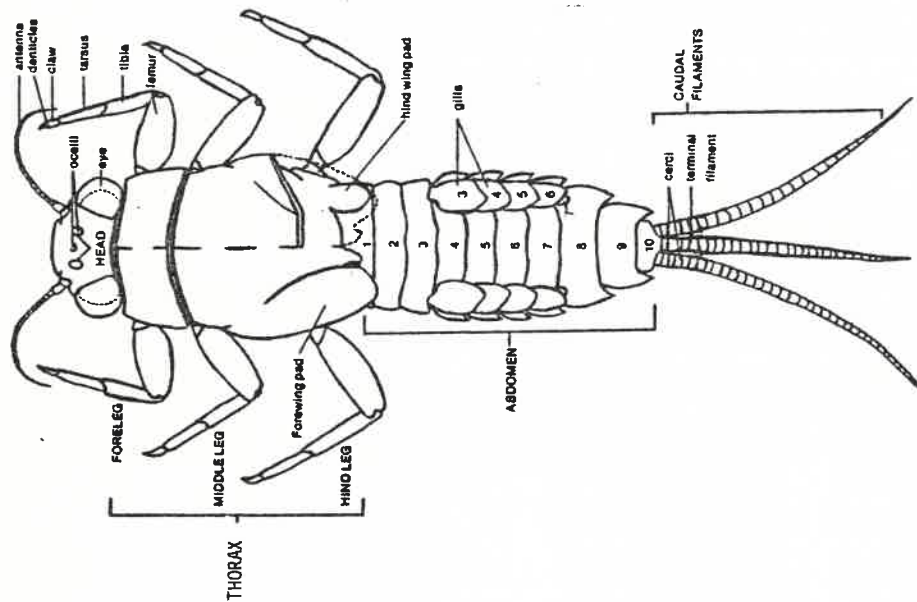


Diagram of Aquatic Insect Larva (Fig. 1)

- | | |
|---|----------------------------|
| 1) Thorax with 3 pairs of segmented legs | 3 |
| Thorax without segmented legs | 2 |
| 2) Mummy-like, in case, often silk cemented | Pupae (not keyed) |
| Not in case, mobile larvae (Fig. 2) | Diptera (true flies) |
| 3) With wings or external wing pads | 4 |
| Wings or external wing pads absent | 9 |
| 4) With large, functional wings | 5 |
| With wing pads | 6 |
| 5) Front wings hard, opaque, shell-like, and without veination (Fig. 4) | Coleoptera (beetle) adults |
| Front wings hardened only in basal half, mostly membranous with conspicuous veination in wing tips (Fig. 5) | Hemiptera (true bugs) |



Fig. 2

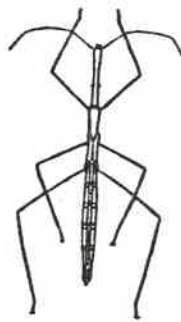


Fig. 3



Fig. 4



Fig. 5

- | | |
|---|---------------------------------------|
| 6) With 2 or 3 long, filamentous terminal appendages (caudal filaments) | 7 |
| Terminal appendages absent or not filamentous | 8 |
| 7) Sides of abdomen with plate-like, feathers-like, or leaf-like gills; usually with 3 tail filaments, sometimes 2 (Fig. 6) | Ephemeroptera (mayflies) |
| Gills absent from middle abdominal segments, 2 tail filaments (Fig. 7) | Plecoptera (stoneflies) |
| 8) Mouthparts include elbowed, extendable clasp organ folded under head (Fig. 8) | Odonata (dragonflies and damselflies) |
| Mouthparts sucking, formed into broad or narrow tube | Hemiptera (true bugs) |



Fig. 6

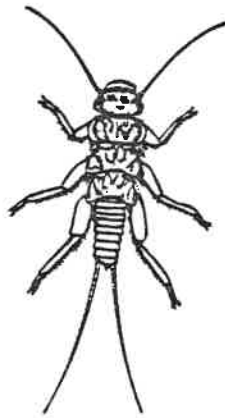


Fig. 7

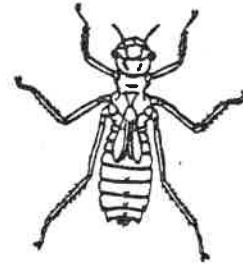


Fig. 8

- | | |
|--|---------------------------|
| 9) Mouthparts sucking formed into narrow tube (Fig. 3) | Hemiptera (true bugs) |
| Mouthparts not formed into narrow tube | 10 |
| 10) Antennae extremely small, inconspicuous, larvae often in case (Fig. 9) | Trichoptera (caddisflies) |
| Antennae elongate, with 3 or more segments | 11 |
| 11) A single claw on each tarsus (terminal leg segment) | Coleoptera |
| Each tarsus with two claws | 12 |



Fig. 9

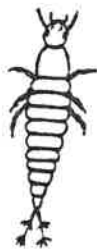


Fig. 10



Fig. 11

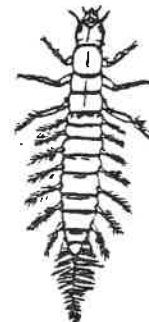


Fig. 12

12) With conspicuous lateral filaments
Without conspicuous lateral filaments (Fig. 10)

13) Abdomen terminating in 2 slender filaments or a
median proleg with 4 hooks (Fig. 11)

Abdomen terminating in a single slender filament or
in 2 prolegs, each with 2 hooks (Fig. 12)

13

Coleoptera (beetle)
larvae

Coleoptera (beetle)
larvae

Megaloptera (dobson
flies and fish
flies)

APPENDIX D

KEY TO FISH OF LAKE SUPERIOR

Terms Used in Keying Fish

- Adipose fin - a fleshy rayless fin posterior to the dorsal fin
- Anal fin - median, ventral fin located just behind the anus
- Barbel - slender, fleshy structures usually located around the mouth
- Caudal fin - the tail fin
- Dorsal fin - unpaired, median fin on the back
- Fin rays - bony structures which support the fin membrane
 - soft rays - flexible rays which are usually branched at outer ends
 - hard rays - stiff sharp spines supporting fin membrane
- Gill rakers - series of projections along the inner edge of the gill bar
- Lateral line - a series of sensory pores appearing as a line usually running on the side of the body from the gill cover to the caudal fin
- Maxillary bones - paired bones forming the posterior part of the rim of the upper jaw
- Pectoral fins - the anterior paired fins
- Pelvic fins - the posterior paired fins

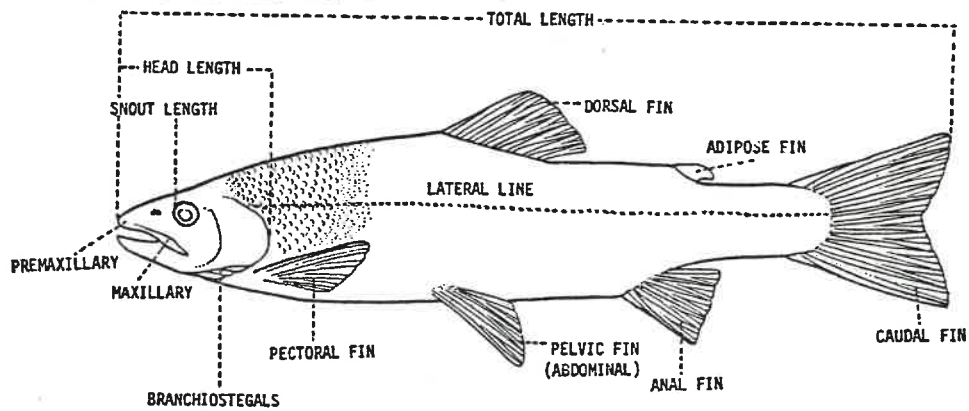


Fig. 1.

- | | |
|---|----------------|
| 1) Adipose fin present | 2 |
| Adipose fin absent | 13 |
| 2) Body scaleless, strong pectoral and dorsal spines, barbels around mouth (Fig. 2) | Catfishes 3 |
| Body scaled, no barbels | 4 |
| 3) Adipose fin short, well separated from caudal fin | Black bullhead |
| Adipose fin simple ridgelike extension of caudal fin | Tadpole madtom |
| 4) Pectoral fin overlaps anterior (front) of pelvic fin | Trout perch |
| Pectoral fin never reaches base of pelvic fin | 5 |

- | | |
|---|--|
| 5) One or two prominent curved teeth on end of tongue
No teeth or tongue | Rainbow smelt
Trout, salmon, &
Whitefish 6 |
| 6) Mouth large, extending to middle of eye or beyond,
teeth strong
Mouth small, not extending beyond middle of eye,
teeth weak | Trout & salmon 7
Cisco & whitefish 12 |
| 7) Anal rays 13-19
Anal rays 7-12 | (Salmon) 8
(Trout) 9 |
| 8) Flesh at base of teeth on lower jaw black
Flesh at base of teeth or lower jaw pale | Chinook salmon
Coho salmon |
| 9) Markings on back light on dark background,
scales inconspicuous
Markings on back dark on light background,
scales conspicuous | 10
11 |
| 10) Caudal fin deeply forked
Caudal fin square or slightly forked | Lake trout
Brook trout |
| 11) Caudal fin distinctly marked with radiating rows of
black spots, body never with red spots
Caudal fin usually unspotted, but never with regular
rows of black spots, body sometimes, with red
spots | Rainbow trout
Brown trout |
| 12) Gill rakers (Fig. 3) less than 32
Gill rakers 43-52 | Lake whitefish
Cisco or Lake
herring |

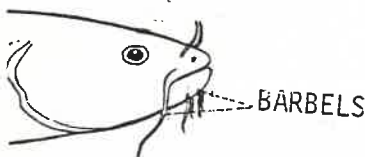


Fig. 2

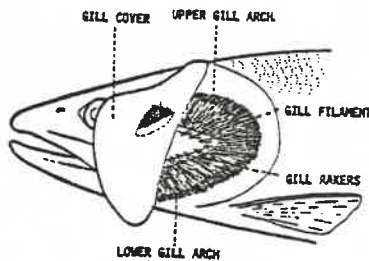


Fig. 3

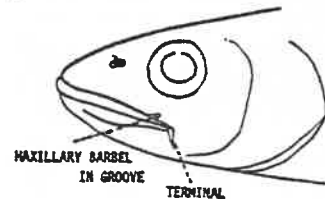


Fig. 4

- | | |
|--|---------------------|
| 13) Dorsal fin 2-10 isolated sharp spines
Dorsal spines joined by membrane | Stickleback
14 |
| 14) Pelvic fins in center of body
Pelvic fins towards front of body (under pectoral fins) | 15
26 |
| 15) Jaws large, teeth well developed
Jaws short, no teeth | Northern pike
16 |

16)	Lips thick and mouth on bottom side of head Lips thin and usually terminal	Suckers 17 20
17)	Scales relatively small, more than 55 in lateral line Scales larger, fewer than 50 in lateral line, color usually silver, occasionally with red fins	18 19
18)	Tip of nose extends well beyond mouth, lateral line scales more than 90 Tip of nose only slightly beyond front of mouth, lateral line scales less than 90	Longnose sucker White sucker
19)	Back of lower lip forms straight line Back of lower lip forms a "V"	Shorthead redhorse Silver redhorse
20)	Lateral line present, not as below Lateral line absent, belly with sharp pointed scales, body deep and thin	Minnow 21 Alewife
21)	Two pairs of long barbels on upper jaw, first ray of dorsal fin is strong spine No barbels, soft fin rays	Carp 22
22)	Barbel at corner of jaw (maxillary) or in groove (may be inconspicuous) (Fig. 4) No barbel	Lake chub 23
23)	Lateral line scales less than 44 Lateral line scales more than 50	24 Creek chub
24)	Anal fin rays 9-12 Anal fin rays 7-8, spot at base of caudal fin	25 Spottail shiner
25)	Front of dorsal fin in front of or over front of pelvic fin, scales twice as high as wide Front of dorsal fin behind front of pelvic fin, scales nearly round	Common shiner Emerald shiner
26)	Head large and slightly flattened, very large pectoral fins, maximum size of 4 inches Not as above	Sculpin 27
27)	Scales inconspicuous, single barbel under chin Scales obvious, no barbel	Burbot 28
28)	Anal spines 1 or 2 Anal spines 3 or more	(Perch family) 29 Rock bass
29)	Mouth large, corner extends to midpoint of eye or beyond Mouth small, corner reaches front of eye at most	30 31
30)	Anal fin with 2 spines and 6-8 soft rays, 6-8 wide, dark, vertical bars Anal fin with 2 spines and 12-13 soft rays	Yellow perch Walleye
31)	Anal fin as large or larger than soft dorsal fin Anal fin smaller than soft dorsal fin, body with small W-shaped markings on side	Logperch Johnny darter

