LIMNOLOGY IN THE NORTH AMERICAN ARCTIC AND SUBARCTIC*

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LIMNOLOGY, the physical and biological study of inland waters, is a comparatively new field and perhaps for that reason it has lagged somewhat during the recent studies of arctic resources. It may be agreed that limnology began about 1870 with Forel's studies in Switzerland. The early work was mainly in temperate areas, first in Europe and later in America. Studies of alpine lakes have resulted in notable contributions to the science as have also several expeditions to tropical lakes, but as yet very little has been done in the Arctic. An examination of the scattered results from arctic work and a survey of the potential areas for study, suggest that freshwater research in the Arctic should prove fruitful in both practical and theoretical fields.

Boundaries of the arctic and subarctic regions have been suggested and redefined by various geographers, climatologists, and plant ecologists. In general the search has been for a mathematical expression of climatic conditions which will produce a line following closely the boundary between forest and tundra. Köppen's (1908) line, joining points where the mean temperature during the warmest month is 10°C, has been improved on by Nordenskiöld's formula (1928) and again by Thornthwaite's line for 33 cm. evapotranspiration (1946). For our present purposes the Arctic can be defined as equivalent to the tundra and arctic icefields. The boundary between forest and tundra is thus the northern limit of the Subarctic but the southern boundary of the Subarctic is more difficult to define. Again, for our purposes we will use Subarctic to mean that northern, thin portion of the boreal coniferous forest, often referred to as transitional forest, open lichen-woodland, forest-tundra, or subarctic woodland, although the proponents of these terms would not consider them equivalent.

The field for arctic limnology

The number and extent of lakes in the North American Arctic is not widely appreciated. An examination of the arctic (tundra) region on the recent 100 mile-to-the-inch map of Canada shows 10 lakes between 500 and 2,200 square miles in area, 40 lakes from 100 to 500, and about 200 lakes between 25 and 100 square miles. Air photographs of the Arctic reveal hundreds of thousands of small lakes which cannot be shown on small-scale maps. It is obvious also, that the many rivers of the Arctic offer important possibilities for limnological investigation.

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Beginning at the west, the arctic lakes of Alaska and the Yukon are mostly small and located in the coastal plain. The District of Mackenzie has a number of arctic lakes and the huge Great Bear Lake close to the arctic boundary. The District of Keewatin has many lakes large and small, with Dubawnt and Baker lakes at its centre. In the Ungava Peninsula of northern Quebec there are numerous arctic lakes including the very deep Crater Lake in the great Ungava crater[1] which has attracted recent attention. Among the most interesting and least known of our arctic lakes are those on the islands in the District of Franklin. Victoria Island has a number of sizeable lakes and Baffin Island has at least 25 including Amadjuak Lake, 1,200 square miles in area, and Nettilling Lake, 2,200 square miles, in which the ringed seal, *Phoca hispida*, is found (Soper, 1928). These large lakes should certainly be investigated by limnological expeditions. The Subarctic is equally well supplied with lakes and in this area are found such great bodies of water as Great Bear Lake and the East Arm of Great Slave Lake.

Practical interest in the fresh waters of the Arctic centres naturally in their use for transportation and their possibilities for fish production. In the past the rivers were the important travel routes and more recently the lakes have provided convenient landing areas for float planes. Unfortunately little use has been made of these landings to examine the lakes. It has been suggested that arctic lakes are relatively unproductive of fish, but this opinion is by no means universal. Many rivers produce important quantities of arctic char.

Arctic lakes are of scientific interest in a variety of ways. A study of regional limnology in the arctic area might do much to clear up several problems of lake classification. The fauna of arctic lakes is of special interest in zoogeographic studies, especially in relation to the problem of relicts and glacial history. Perhaps the most fundamental problem is that of the physical and chemical conditions involved in the productivity of arctic lakes.

Past and present studies in arctic limnology

Many useful observations on the limnology of arctic fresh waters can be culled from general accounts of surveys or exploration and from technical reports in various scientific fields. Thus Porsild (1945 and elsewhere) provides useful notes on the small lakes in the Mackenzie delta and Eskimo Lakes basin and records a brief examination of Yathkyed Lake (1936). Soper (1928) explored parts of Nettilling and Amadjuak lakes on Baffin Island. However, studies which are primarily limnological are rare in the North American Arctic[2] and relatively few in the Subarctic.

Recent studies of the small arctic lakes in the Alaskan coastal plain have been concerned with a variety of problems, for example, orientation (Black and Barksdale, 1949), ice conditions and lake formation (Hopkins, 1949; Stone, K., unpubl.), lake history from pollen analysis (Livingstone, unpubl.), algae (Croasdale, unpubl.), and productivity (Comita, unpubl.). Far to the east, in Ungava, some freshwater investigations have been initiated by Dunbar

[1]Now officially named New Quebec Crater, sometimes referred to in the past as "Chubb Crater".

[2]Since this paper was written several studies have been carried out in the Alaskan Arctic. *Ed.*

(1951a) in addition to his important marine studies. In 1951 Martin (unpubl.) made interesting observations on Crater Lake, also in Ungava. Between these widely separated localities lie the Northwest Territories in which there appears to be no current project on arctic lakes.

In the Subarctic, mention should be made of the pioneer work on Karluk Lake, on Kodiak Island, Alaska, by Juday and others (1932). This was the first intensive limnological study in the far north of America though Bachmann's work in Greenland dates back to 1908. Teslin Lake, on the Yukon–British Columbia boundary was investigated by Clemens and others (1945). Great Bear Lake was surveyed by Miller and Kennedy in 1945, as reported by Miller (1947). My own work on Great Slave Lake (1950) is of some interest in this connection although only the East Arm should be regarded as in typical subarctic surroundings. Clarke (1940) and Bardach (1952, unpubl.) have provided information on lakes in the Thelon region, east of Great Slave Lake, and Harper (1948) has reported on Nueltin Lake just north of the Manitoba boundary. Thus a modest beginning has been made in the limnological investigation of the Subarctic, a situation which might suggest that new work in the near future should be concentrated on lakes in the Arctic proper.

Possible contributions from arctic limnology

The investigation of arctic lakes should contribute to the solution of some basic problems in limnology. Forel's early classification distinguished as polar, those lakes in which the surface temperature did not rise above 4°C. This polar type and certain subdivisions which have been suggested, are not much used by limnologists. Most of the lakes in the Subarctic would be classified as "temperate" under the Forel system. Knowledge of deep temperatures as well as surface, and of water circulation is needed in order to arrive at a satisfactory thermal classification. At the present time we lack not only information on water temperatures, but even data as to the usual dates for open water in many of our arctic lakes. Tyrrell (1909) suggested that Dubawnt Lake was always more or less completely covered with ice at the end of last century. However, Porsild (1936) reports Yathkyed clear of ice at the end of July, also that large lakes on Banks and Victoria islands were ice-free by mid-August in 1949 (1950). Soper (personal communication) reports that Nettilling and Amadjuak lakes on Baffin Island are usually free of ice about the beginning of August and remain open for a maximum of two and one-half months. Small shallow lakes are free of ice much earlier in the season.

The trophic classification of lakes is probably of greater interest than the thermal since it is more closely related to productivity. Extremes of low temperature might be expected to impose a degree of oligotrophy on most of the lakes in an arctic area. Livingstone (1951, unpubl.) mentions Chandler Lake, in the Brooks Range of northern Alaska, as very oligotrophic. However, Andersen (1946) found lakes in northeast Greenland which were moderately eutrophic in spite of a very short summer season and low temperatures. He also records severe winter stagnation during the long period of ice cover.

The innumerable shallow lakes and ponds of the Arctic are often described as teeming with cladocerans, phyllopods, insect larvae, and worms. Apparently these should be regarded as eutrophic. Their surface temperatures may exceed 15°C and can reach this within a few days of the disappearance of the ice. Many small ponds freeze to the bottom in winter and have no inlets or outlets so they are lacking in fish. Johansen (1922) refers to a lake near Bernard Harbour with a maximum depth of 20 feet and an ice thickness of "almost ten feet". In this lake he found trout (*Salvelinus*) and sticklebacks. Even in lakes lacking fish the great production of invertebrates may be of importance to man, since it attracts many species of shore birds and waterfowl.

Water circulation is probably complete during the open water season in the many shallow arctic lakes. Little is known about circulation in deep arctic lakes. However, Martin (personal communication) reports that on 31 July 1951 Crater Lake was homothermous at 2.55°C from 10 to 135 metres depth. The surface temperature was 2.9°C. Unfortunately no analysis was made of deep-water oxygen but such homothermy suggests the probability of deep mixing. The total solid content of a sample of lake water contained approximately 15 p.p.m. of which approximately one-third was organic material. Interesting cases of meromixis (incomplete circulation) are found in coastal lakes which have at some time received salt water. Johansen (1911) reports this condition in Sælsøen in northeast Greenland and Dunbar has recently investigated a similar situation in Ogac Lake, at Ney Harbour, Frobisher Bay.

It will be of interest to compare the productivity of arctic lakes with that of arctic marine waters. The standing crop of plankton in truly arctic marine waters is low, presumably because of temperature. In nearby subarctic waters it may be from three to six times as great (Dunbar, 1951b). Is there a similar difference between the productivity of arctic and subarctic fresh waters? Clarke (1940) expresses the opinion that although arctic lakes may appear to have heavy fish populations, they will not support much fishing because of the short season and slow growth of fish. However, Kennedy (1953) finds that the scales of whitefish of Great Slave Lake show nearly half their growth during the first two weeks of August. This very rapid growth in the short season allows the population to support a very extensive commercial fishery. The ice on small arctic lakes melts early and allows a rich growth of plants and animals. In the larger lakes of the far north the ice cover lingers reducing the potential growth period for plankton.

The progressive warming of northern areas has caused a great increase in the fish production of northern marine waters, for example the increased cod production in the Greenland area. It would be of interest to discover whether the fresh waters of the Arctic are undergoing a similar change in productivity.

Arctic and alpine areas have much in common and we are in the habit of speaking of alpine–arctic conditions. The extent to which this resemblance is shown in lakes should be investigated. Arctic lakes are exposed to very different light conditions and, in general, to much lower precipitation than are the high alpine lakes of temperate latitudes.

Zoogeographic studies in the North American Arctic have been concerned mostly with marine organisms. Information as to the distribution of some freshwater invertebrates is presented in the various reports of the Harriman Alaska expedition, the Canadian Arctic expedition, and in many miscellaneous papers. Wynne-Edwards (1952) has provided an excellent summary of the present knowledge of freshwater vertebrates (excluding the birds) of the Arctic and Subarctic. However, the fauna both vertebrate and invertebrate, of the inland lakes of arctic America is still largely unexplored.

Some suggestions for limnological research in the Arctic

It would appear that in the past little consideration has been given to the need for research in arctic limnology. The program of desirable scientific investigations in the North American Arctic, prepared by the Arctic Institute in 1946, makes no reference to limnology, although it deals in some detail with numerous fields of biology. In 1950 the First Alaskan Science Conference urged wildlife research and the investigation of water supply, vegetation, etc., but again the report makes no reference to limnology.

Assuming that the good beginnings in Alaska and in the Ungava–Baffin areas are to be continued and expanded, it would seem that we should begin at once to fill the great gap which lies between. Much information has been obtained concerning arctic lakes in Greenland (various authors publishing in *Meddelelser om Grønland*) and in northern Norway (e.g., Strøm, 1934). Important fundamental studies are being carried on by Ekman, Rodhe, and others on arctic lakes near the laboratory at Abisko, in Swedish Lapland. Vibe (unpubl.) has been working for several years on the freshwater fauna of southwest Greenland. Thorson (1946) urges the extension of ecological studies of fresh water in the high Arctic and makes special reference to the problem of oxygen supply under the ice of lakes. We do not know the extent to which these findings may apply to lakes in northern America.

A broad attack on the problem might be made by equipping one or two parties for a reconnaissance of lakes in the Canadian Eastern and Western Arctics. Such a program might be worked in conjunction with other surveys or investigations in order to share the costs of transportation. The itinerary could be quite flexible since the whole area is practically unknown from the limnological point of view. Two or three summers of this kind of work should provide invaluable data as to depths, temperatures, chemical, physical, and biological conditions, and the distribution of aquatic organisms.

More intensive investigations might be started at once in a few selected arctic lakes, differing in areas and depths and located possibly in the District of Keewatin, as the centre of limnologically-unknown territory. Studies of these lakes should continue through the open-water season and any opportunity for winter sampling should be seized since some of the more important problems can be solved only by knowing conditions under the ice. It should be made clear that while faunistic studies can be advanced by casual and irregular collecting, real progress in limnology can be expected only as a result of continued and intensive studies.

It was suggested above that the Ungava work should be continued and expanded. One of the more obvious needs is a study of the freshwater fauna of the Ungava-Labrador Peninsula. Such an investigation would determine the northern limits of temperate species and might demonstrate the effect of height of land as a factor in distribution. It would be of particular interest to see whether any zonation observed in freshwater organisms agreed with the plant cover classifications proposed for this area by Rousseau (1952), Hustich (1949), and Hare (1950).

An arctic river should also be selected for careful study of its physics, chemistry, and biology. The river chosen should have a good population of that important fish species, the arctic char. A preliminary study of the char was made by Sprules (1952) near Chesterfield Inlet, and a second by Grainger (1953) in Frobisher Bay, south Baffin Island. Further study might be made in a stream in the Western Arctic with comparative observations on a land-locked population. General studies of the distribution of freshwater fish in the Arctic are much needed.

It would seem that, if workers in different fields of arctic investigation would make known their needs, they might cooperate in obtaining vital information. Perhaps plant ecologists, geologists, and others might be willing to record depth and temperatures and to take samples of plankton if suitable equipment were provided. In return, limnological field parties might collect specimens and obtain seasonal data in botanical and meteorological fields. An excellent illustration is provided by Porsild (1932). In the spring of 1928, while engaged in botanical studies, he observed and made accurate measurements of seiches under the ice in the Dease Arm of Great Bear Lake.

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