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O F C A N A D A

MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No.

523

Title

Factors affecting the infection of the whitefish,  
Coregonus clupeaformis (Mitchill),  
by the tapeworm, Triaenophorus crassus Forel,  
in the Thunder Bay District of Ontario

Author

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Central Fisheries Research Station

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# FISHERIES RESEARCH BOARD OF CANADA

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by the Tapeworm, Triaenophorus crassus Forel,  
in the Thunder Bay District of Ontario

by

Harold E. Welch

A thesis submitted in conformity with the requirements  
for the Degree of Master of Arts  
in the University of Toronto

This work carried on under the auspices of the  
Fisheries Research Board of Canada

## INTRODUCTION

A common parasite in Canadian whitefish is the cestode, Triacnophorus crassus Forel. Many aspects of the life cycle of this parasite have been investigated, but no direct study of the factors influencing the infection of whitefish has been made. The principal object of this investigation was the examination of physical and biological factors involved in the complexity of this host-parasite relation. Another objective was to provide information useful in the designing of management programmes for the partial or complete elimination of the tapeworm and the consequent improvement of the quality of whitefish.

## ACKNOWLEDGEMENTS

This investigation was carried out under the direction of Professor J. R. Dymond, Department of Zoology, University of Toronto. I am grateful to Professor Dymond for his encouragement, advice and criticism in the preparation of this thesis.

Field expenses for this project, a co-operative research programme, were borne jointly by the Fisheries Research Board of Canada and the Ontario Department of Lands and Forests. To Dr. K. H. Doan and his staff at the Central Fisheries Research Station, Winnipeg, I wish to express my thanks for their assistance and for the facilities extended to me. I am indebted to Dr. W. J. K. Harkness of the Department of Lands and Forests for the ready co-operation and assistance that he and the members of his staff rendered to me. In particular, I should like to thank Mr. C.W. Douglas,

Biologist, and Mr. G. Clifford, Field Officer, of the Department of Lands and Forests for their assistance in my field work.

The preparation and writing of this thesis was made possible by a Research Grant from the Research Council of Ontario. I should like to acknowledge my thanks to the Council and to its Director, Professor J. O. Wilhelm.

I should like also to express my appreciation to Dr. W. B. Scott of the Royal Ontario Museum of Zoology for his inspiration and suggestions throughout the project. Assistance in statistical analysis was gratefully received from Dr. L. Butler, University of Toronto. For advice in the parasitological aspects of the problem, and for constructive criticism of the thesis, I am grateful to Dr. A. M. Fallis of the Ontario Research Foundation. I am similarly indebted to Dr. F. E. J. Fry, University of Toronto, for his suggestions and criticism in the preparation of this manuscript.

Graduate students in the Department of Zoology have given assistance in various ways. I am very grateful to them, and especially to Mr. A. McCombie for help in the identification of plankton.

The kindness of Mr. J. McKirdy of Fort William and of Mr. F. Arnold of Port Arthur in allowing the use of their camps, as well as the assistance of the Lake Nipigon fishermen is sincerely appreciated.

## THE WHITEFISH, COREGONUS CLUPEAFORMIS (MITCHILL)

### Systematic Position

The common whitefish, Coregonus clupeaformis (Mitchill), is usually regarded by American ichthyologists as belonging to the family Coregonidae, of the order Isospondyli. Other North American members of the family Coregonidae are Leucichthys spp., the ciscoes, tullibees, or lake herrings; Prosopium spp., the round whitefish; and Stenodus leucichthys, the inconnu.

Two forms of whitefish are often referred to by authors and fishermen; viz., the deep-water and the shallow-water forms. Dymond (1923) describes the latter as a darker, slimmer fish than the former. Fishermen at Lake Nipigon recognize these forms and have reported to the author that the shallow-water form spawns earlier than the deep-water form, and in rivers and streams rather than on open lake shoals as is the case with the deep-water form. These two types are not recognized taxonomically.

### Geographical and Ecological Distribution

The genus Coregonus is distributed generally throughout the northern hemisphere (Meek, 1916). The range of the common whitefish, C. clupeaformis, extends from the Arctic Ocean to the northern states of the United States, and from the Rocky Mountains to the Maritime Provinces (Dymond, 1947).

Whitefish are freshwater fish, although sea-run members of the species occur in the Hudson Bay region (Dymond, 1932).

Typically lake fish, they are found in clear, cool water at moderate depths.

### Economic Importance

Whitefish have been of great importance to Canada's development. Many early explorers and fur traders depended on the whitefish for food for both man and sled dog. Today whitefish are the most economically important freshwater fisheries of Canada.

In 1948, 19,909,000 pounds of whitefish were caught and landed

with a market value of \$4,988,000. When compared with other

Canadian fisheries, whitefish production ranks seventh in commercial value, contributing approximately four per cent of the total value of the Canadian fisheries catch of 1948.

In Ontario whitefish rank highest in production and value. The landed whitefish poundage of 6,539,000 pounds in 1948 had a market value of \$2,016,050 and was approximately 35 per cent of the total value of Ontario fisheries.

### Life History

Whitefish are fall spawners. Spawning usually occurs in late October and early November on shallow rocky shoals. During the spawning period the fish swim off the bottom and take little food.

Hatching occurs about the middle of April. The fry are active swimmers and keep near the surface. Hart (1930) reports that schooling tendencies are evident within two weeks after

hatching at which time the fry tend to congregate in shallow water of 18 inches or less in depth. By the fourth week the fish venture into deeper water of three or four feet, but always remain near the surface. By the end of May, no whitefish are to be found inshore. Hart (1930) believes that they must move to the bottom of medium depth water, as he has taken several specimens in this habitat. In these early stages, the whitefish feeds on plankton, (Forbes, 1883; Hart, 1930). As it grows, it gradually becomes a bottom feeder until at a mature size its diet is generally benthic. Nektonic organisms are seemingly accidental items. There are records of whitefish feeding on small fish, (Clemens, et al., 1923).

Whitefish attain sexual maturity at different ages in different bodies of water. Hart (1930) considers that the whitefish in Lake Ontario become mature in their fifth or sixth year. It is generally recognized that Lake Erie whitefish attain maturity in their third or fourth year.

### Movements

Schooling--There is considerable evidence to support the belief that whitefish travel in schools. In a gang of nets usually two or three nets will catch most of the fish taken by the gang. Koelz, in his 1929 study, gives a lengthy discussion of the schooling behaviour of whitefish.

Seasonal--The fall movements of whitefish are usually spawning runs into shallow water. The other movements, especially

those of the spring, are of importance in Triaenophorus parasitism.

Koelz (1929), page 521, describes the movements of Lake Michigan whitefish as follows:

"As soon as the ice leaves, the fish are driven to the deepest water in which they ever are taken abundantly; namely, 20 to 30 fathoms. Individuals stray into deeper water occasionally during any season, and specimens have been caught in 60 fathoms or even deeper... When the water begins to warm, they approach the shores, and in July, in most localities, they are taken most abundantly in the pounds at depths of 16 to 65 feet (3 to 11 fathoms). In July and August the gill-nets take them best at 10 to 20 fathoms. In fall they come ashore again and are taken best first by the pound nets and later, when they are spawning, by gill-nets. During winter they probably remain near shore under the ice, but when the ice breaks they are driven to deeper water, possibly by the heavy shore currents at this time or in quest of food."

These observations are in accordance with those of the author, made through either personal observation or conversations with fishermen on Lake Erie, Lake Huron, Lake Superior, and Lake Nipigon.

### Parasites

Whitefish have parasites other than Triaenophorus. Hart

(1931), in an examination of 113 whitefish from Lake Ontario, found 108 (95 per cent) of them parasitized. Almost identical results were obtained by Bangham and Venard in 1946 in their investigation of whitefish from a series of lakes in Algonquin Park, Ontario. Bangham and Hunter (1939) obtained a somewhat lower figure of 88 per cent infection for the whitefish of Lake Erie.

Although the incidence of parasites is high, the number of species of parasites infecting whitefish is relatively small in

comparison with the number of species of parasites found in some other fish. Among the cestodes, various members of the genus Proteocephalus are common in whitefish of the aforementioned localities. Cystidicola sp. is a common nematode parasite, while Echinorhynchus, an acanthocephalan, and Crepidostomum sp., a trematode, are other common forms.

### THE TAPEWORM, TRIAENOPHORUS CRASSUS FOREL

#### Systematic Position

Triaenophorus is a genus of pseudophyllidean cestodes, which spend a portion of their life history in copepod crustaceans and in teleost fish.

Three species of Triaenophorus are recognized today in the North American cestode fauna; viz., T. crassus Forel (1880), T. nodulosus (Pallas) (1760), and T. stizostedionis Miller (1945). The three species can be distinguished by differences in the shape of the hooks on the scolex, and in the structure of the male genitalia. Each species has a different second intermediate host.

#### Geographical Distribution in North America

T. crassus is found throughout the three Prairie Provinces, in northern Ontario, and in the Northwest Territories. Surveys in southern Ontario by Hart (1931), Bangham and Hunter (1939) and Bangham and Venard (1946) do not list T. crassus. From these investigations it would seem that T. crassus does not occur in the

whitefish of southern Ontario. Cooper (1918) records T. robustus, a name in synonymy with T. crassus, as occurring in pike, Esox lucius, and in burbot, Lota lota maculosa, caught in Georgian Bay. Bangham (1951) found T. crassus in fish taken from waters adjacent to Manitoulin Island in Lake Huron and in lakes on the island.

Several authors record T. nodulosus in Ontario and in the Prairie Provinces. Choquette (1951) records it in the St. Lawrence River and adjacent waters. In United States, Cooper (1918) records the species in Michigan; Hjortland (1928) reported the worm in Minnesota; and Fischthal (1945) found specimens in fish of Wisconsin Lakes.

T. stizostedionis has been found in fish of Ontario, Manitoba, Alberta, the Northwest Territories and Minnesota.

#### Economic Importance

Triaenophorus has not been recorded as infecting man or other mammals, despite that fact that large quantities of coregonine fish are consumed in the Canadian west by both man and beast, Newton (1932).

The chief objection to T. crassus is the repugnant appearance of the plerocercoid cysts in the flesh of the second intermediate hosts, ciscoes and whitefish. This feature has decreased the commercial value of these fish, as badly infected fish cannot be marketed. This is particularly true with regard to the export of coregonine fish to United States markets. The United States Food

and Drug Administration has imposed severe import restrictions on Canadian whitefish. These restrictions seriously threaten the continuation and development of the Canadian whitefish industry. In view of this, the Canadian authorities have instituted regulations and supported investigations designed to improve the quality of whitefish.

Table I. Hosts for three species of *Triaenophorus* in Canada.

| Species                  | 1st Intermediate host                                                                        | 2nd Intermediate host                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Definitive host                                                            |
|--------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| <u>T. crassus</u>        | <u>Cyclops bicuspidatus</u>                                                                  | <u>Petromyzon marinus</u> <sub>14</sub><br><u>Leucichthys tullibeei</u> <sub>2</sub><br><u>L. zenithicus</u> <sub>3,10</sub><br><u>L. nipigon</u> <sub>3,10</sub><br><u>L. nigripinnis</u> <sub>3,10</sub><br><u>L. artedii</u> <sub>1</sub><br><u>L. hoyi</u> <sub>15</sub><br><u>Coregonus clupeaformis</u> <sub>3</sub><br><u>Prosopium oregonium</u> <sub>7</sub><br><u>Cristivomer namaycush</u> <sub>8</sub><br><u>Stenodus leucichthys</u> <sub>8</sub><br><u>Esox lucius</u> <sub>7</sub><br><u>Lota lota maculosa</u> <sub>1</sub> | <u>Esox lucius</u> <sub>4</sub>                                            |
| <u>T. nodulosus</u>      | <u>Cyclops bicuspidatus</u> <sub>5</sub><br><u>Cyclops strennus</u> <sub>5</sub><br>(Europe) | <u>Perca flavescens</u> <sub>1,11</sub><br><u>Lota lota maculosa</u> <sub>6</sub><br><u>Micropterus dolomieu</u> <sub>1</sub><br><u>Catostomus commersoni</u> <sub>1</sub><br><u>Cottus cognatus</u> <sub>12</sub>                                                                                                                                                                                                                                                                                                                          | <u>Esox lucius</u> <sub>4</sub><br><u>Esox masquinongy</u> <sub>1,13</sub> |
| <u>T. stizostedionis</u> | <u>Cyclops bicuspidatus</u> <sub>9</sub>                                                     | <u>Percopsis omiscomaycus</u> <sub>9</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <u>Stizostedion vitreum</u> <sub>9</sub>                                   |

## References

1. Cooper, 1918
2. Hjortland, 1932
3. Newton, 1932
4. Miller, 1943a
5. Miller, 1943b
6. Miller, 1945a
7. Miller, 1945b
8. Miller, 1945b (Rawson)
9. Miller, 1945c
10. Keleher, 1950
11. Lawler, 1950
12. Lawler, 1951
13. Choquette, 1951
14. Bangham, 1951
15. Welch, 1951

## Life History

Table 1 gives a synopsis of the known hosts recorded for the species of Trienophorus found in Canada.

The three species of Trienophorus have similar life cycles. Proceroids of all three have been found in the copepod, Cyclops bicuspidatus. Plerocercoids of each species are found in a different host. Both T. crassus and T. nodulosus share the same definitive hosts, the former commonly occurring in pike of three or more pounds weight, the latter being found in smaller pike of less than this weight, Miller (1943a). Miller also reports cases in which mixed infection occur.

As this study is chiefly concerned with T. crassus, its life cycle in Canada and its infection of coregonine fish will be discussed in more detail.

Adult tapeworms in the intestinal tract of the pike release their eggs at a time which coincides with the pike spawning in the spring. These eggs hatch to produce free-swimming ciliated larvae called coracidia, which are in turn ingested by copepods. They penetrate the gut by means of coracidial hooks and enter the

body cavity. In about ten days they attain their maximum size, after which they are known as mature procercoids (Miller, 1945b).

If a coregonine fish swallows an infected Cyclops, the procercoid is released in the gut of the coregonine. The larvae then moves from the gut to the musculature of the fish where it becomes encysted. Specimens which were not encysted have been reported, (Lawler, 1950).

The larva then enters the plerocercoid stage of its life cycle. Miller (1945b) describes this stage as follows:

"Each cyst consists of a wall of connective tissue supplied by the host; inside, surrounding the coiled plerocercoid, is a thick albuminous fluid made up of digesting host tissue and excretory products from the worm. The cysts are extremely variable...(in size and shape)...The cysts occur in the myomeres; usually one cysts is wholly within a myomere but occasionally a cyst extends across two...The plerocercoid is a long (up to 300 mm.), thin (1 mm.), unsegmented worm that has a fully developed scolex similar to that of the adult. Young plerocercoids still possess a frontal gland, which opens at the tip of the scolex. Sex organs are never developed. Often a cauda is present; this is a posterior appendage of variable length, characterized by poorly developed muscles and parenchyma and presenting a degenerate appearance. The great variability of the plerocercoid and its cauda appears to be related to age."

The distribution of cysts within the host has been studied by Newton (1932) who found that 60 per cent of the cysts were located in the anterior dorsal musculature of the body.

In the course of pike predation on coregonine fish, the tapeworm is transferred to its definitive host, and, as an adult, produces its eggs, thus completing its life cycle.

### Host Specificity

From Table I it may be seen that C. clupearformis is but one of the intermediate hosts for T. crassus. Miller (1945d) has found that T. crassus exhibits some degree of host specificity for Leucichthys spp.

### TRIAENOPHORUS AND FISHERY MANAGEMENT

Various government agencies have financed research and passed legislation designed to improve the quality of whitefish. Consequently, there are laws governing the export of infected fish, the inspection of fish, the licensing of fishermen, and the control of fishing in infected lakes. Fishermen, themselves, have attempted control measures through selective fishing, and methods of processing. Several biological controls have been attempted.

The biological control measures may be subdivided according to the four phases in the Triaenophorus life cycle.

Attacks upon the coracidial stage have been aimed at the production of conditions lethal to the survival of the coracidia through the manipulation of physical factors. Miller and Watkins (1946) attempted to break the life cycle of the parasite by increasing the acidity of a lake to a level lethal for coracidia. Their attempts proved unsuccessful. Libin (1950) has had some success in the laboratory with a poison as a killing agent, but field tests have not yet been conducted.

Few control measures against the proceroid stage have

been carried out, for little is known concerning this phase of the life cycle.

Knowledge, gained from studies of cisco and whitefish infection, has allowed investigations concerning control measures of the plerocercoid phase of the parasite's life cycle.

Different infection rates between Leucichthys and Coregonus suggested to Miller (1944) that a decrease in the cisco population of a lake would lead to a decrease in Triaenophorus infection in ciscoes and whitefish. Through the co-operation of the Alberta government, an experiment to test this hypothesis was conducted on Lesser Slave Lake. Miller (1948) records that intensive removal of ciscoes was followed by a decrease in the average weight of the ciscoes, as well as a significant decrease in the Triaenophorus cyst incidence of whitefish. In three years the average cysts per 100 whitefish decreased from 265 to 26, and the percentage of infected fish in the samples dropped from 30.8 per cent to 6.8 per cent. This experiment has been the most promising to date, for it shows positive results under actual field conditions.

Other experiments, designed to test the same theory and carried out in Saskatchewan by biologists of the Fisheries Research Board, did not show similar decreases in cyst count as was observed by Miller.

The cisco removal problem is further complicated by the existence of a number of species of cisco which Keleher (1950) reports as having different degrees of infection.

As the adult tapeworm lives in the intestine of the pike,

Esox lucius, the removal of this host would theoretically prevent the parasite from completing its life cycle. Several experimental programmes have been carried out in an effort to test the validity of this theory.

Scheuring (1922) recommended from his studies of Triaenophorus nodulosus in Europe that pike reduction should be used as a method of control for this parasite in trout hatcheries. Newton (1932) after investigations conducted in Manitoba reported that pike removal was a method of control for T. tricuspidatus (syn. T. crassus), but limited in that "it was practically impossible to eliminate the pike except here and there".

Experiments conducted by biologists of the Fisheries Research Board at Heming Lake in Manitoba have shown that there was a decrease in the degree of infection when the pike population was reduced, (Lawler, 1950, 1951). Pike removal per acre has been more or less constant over the last seven years and has resulted in a decrease in the number of cysts per whitefish, but in little change in the number of cysts per 100 pounds of fish. Lawler (1951), in reviewing the data, considers that "increased exploitation of the pike population is necessary to effect a substantial decrease" in the degree of infection of the whitefish.

A similar experiment was carried out in Alberta. In this case poison was used to kill the pike populations congregated on spawning grounds in the spring. There was a measurable reduction

in the cisco infection, but the cost of the operation prohibits its use on an extensive scale.

## MATERIAL AND METHODS

### Collection of Materials

Materials for this study were collected during the summers of 1950 and 1951 from four lakes in the Thunder Bay District of Ontario.

During the summer of 1950, studies were carried out on

Lakes Onaman and Muskeg. Lake Onaman is in the Nipigon-Onaman

Crown Game Reserve at latitude  $50^{\circ}$  N. and longitude  $87^{\circ} 30'$  W.

Lake Muskeg is farther south and west at latitude  $49^{\circ}$  N. and

longitude  $90^{\circ}$  W. Research was conducted on Lake Onaman in the period from June 6th to July 15th, and at Lake Muskeg from July 17th to August 11th.

Lake Nipigon was the centre of research in the summer of 1951. In addition to the lake itself, a small lake on one of the islands in Lake Nipigon was investigated. This lake, Shakespeare Island Lake, is located at latitude  $49^{\circ} 37'$  N. and longitude  $88^{\circ} 23'$  W.

Three field trips were made to Shakespeare Island Lake; the first from June 20th to June 30th, the second, an aeroplane trip, on July 31st for the purpose of taking limnological readings, and the third from the 27th to the 30th of August.

For research purposes Lake Nipigon has been divided arbitrarily into seventeen areas. One of these areas, hereafter

referred to as the Sample Area, was studied during the four summer months of June, July, August, and September. The Sample Area is that region of Lake Nipigon which is bounded on the west by a line extending northerly from Gros Cap to the south-eastern corner of Kelvin Island; on the north by a continuation of this line drawn easterly from the south-eastern corner of Kelvin Island to Katatota Island; on the east by a line drawn from this island to Hat Mountain; and, on the south by a line extending westward from Hat Mountain to Gros Cap. (See Figure 4). Samples were obtained also from other areas of the lake during the month of July.

#### Limnological Investigations

Limnological studies were conducted on Lake Oraman, on Lake Muskeg, and on Shakespeare Island Lake. No attempt was made to conduct such a study on the Sample Area in Lake Nipigon. Limited

time and facilities prevented an effective investigation which would probably have added little to the present knowledge of the lake as described by Clemens (1923), Bigelow (1923) and MacKay (1951).

Little limnological data were available on the other three lakes. Maps of each lake had to be drawn and the depths charted. In addition, notes were made on the nature of the shore and surrounding country, on the kinds and extent of aquatic vegetation, and on the number and size of inflowing and outflowing streams.

The limnological attributes investigated on each lake included temperature, hydrogen-ion concentration and water transparency. A faunal survey of the plankton was also carried out.

In the three lakes temperatures were measured with a standard deep-sea reversing thermometer. These temperatures were recorded for a series of depths at four to seven stations in each lake. Those readings were averaged and plotted to give a temperature curve for each week in which research was conducted at a particular lake.

The hydrogen-ion concentration was determined by using a Lamotte H-ion comparator set, calibrated from 6.0 units to 7.6 units. At each station pH readings of both surface and bottom water were made. Water samples were taken with a Kemmerer water sampling bottle.

A Secchi disc was used to determine water transparency. The depths at which the disc disappeared and re-appeared were recorded in feet. The average of these two readings was taken as the value. Incident sunlight readings were taken with a Weston photographic meter in an effort to provide standardization for the Secchi disc readings.

Plankton samples were taken by means of a plankton tow net. This net had a 33 centimetre canvas sleeve, and a bolting cloth cone of 70 centimetres length made of number 20 silk bolting cloth. Vertical plankton hauls were made weekly at each temperature station. A number of horizontal tows were also made. Plankton sampling was done on a qualitative basis.

## Fisheries Investigations

### Sampling Methods

In 1950 a gang of experimental nets was used to take fish for examination in this study. These nets were 50 yards in length and had a stretched mesh range of  $1\frac{1}{2}$  inches to  $4\frac{1}{2}$  inches. Sixty-three net-nights were recorded on Lake Onaman, while 93 net-nights were recorded for Lake Muskeg. A net-night may be defined as one standard experimental net set for one night.

In 1951 fish were obtained from both experimental and commercial nets. Experimental nets were used exclusively in Shakespeare Island Lake. Eleven nets of a stretched mesh size range of  $1\frac{1}{2}$  inches to  $5\frac{1}{2}$  inches composed the experimental gang. In the Lake Nipigon Sample Area two experimental net sets were made. In each case a different number of nets composed the gang. On August 8th a seven-net gang was set for four nights. This gang was composed of one net each of 2,  $2\frac{1}{4}$ , 3,  $4\frac{1}{2}$ , and 5-inch mesh, and of two nets of  $2\frac{3}{4}$  inch stretched mesh. The nine-net gang, used on September 14th, had the same nets plus two additional  $2\frac{3}{4}$  inch stretched mesh nets. One hundred fish were purchased each month from the commercial fisherman who was currently fishing in the Sample Area. These fish were caught in the commercial  $4\frac{1}{2}$ -inch stretched mesh nets. The fishermen were requested to bring in 100 fish just as they were taken from the nets, regardless of size and condition. This, it was felt, would give a representative sample of fish caught by the  $4\frac{1}{2}$  inch stretched mesh net. In

addition, one sample of approximately 100 whitefish was obtained from each of thirteen of the seventeen areas into which Lake Nipigon had been divided. These were purchased between July 12th and July 26th from the fishermen who had been given the same instructions as above regarding the method of procuring the sample. These fish were caught in commercial  $4\frac{1}{2}$  inch stretched mesh nets.

#### Fish Measurements

Measurements were recorded on coin envelopes. Weight and length were the two principal measurements taken. Weight was recorded in ounces. Two measurements of length were taken, the standard length in millimetres and the fork length in inches. Sex determinations and cyst counts were also recorded on the envelopes.

Sex was determined by examination of the gonads. The presence of eggs identified females, while opaqueness and a smooth creamy-white colour of the gonads indicated males. In cases of doubt, the fish were classified as immature. No attempt was made to sex immature specimens.

#### Age Determinations

Scales were collected from the left side of the fish above the lateral line, and below the dorsal fin. The scales were stored in coin envelopes. Eight or ten scales were mounted 'dry' between two 2" x 3" microscope slides and magnified by a Bausch and Lomb projector. A magnification of 45 was found to be the best for efficient scale reading.

All fish scales were read once. Then, scales from every

fifth fish were re-read. Reference was made next to weight and length. Any seemingly inconsistent readings resulting from this comparison were again re-read. At this point a definite age was assigned to each fish. In several cases definite ages could not be assigned as the scales did not admit of accurate age assessment. These fish were discarded in any considerations involving age.

In an effort to determine the limits of accuracy of the readings, the author examined his age determinations and found that there was a 75 per cent concordance between the first and second age determination. In those cases of dissimilar readings, it was found that the disagreement was of one year generally. Thus, individual age determinations for fish of less than twelve years of age may be in error by one or possibly two years. Scales of fish of more than twelve years of age are difficult to read with accuracy since they show little growth and a consequent crowding of annuli, two factors which make accurate reading extremely difficult.

Ages were recorded as the number of completed years. For whitefish a complete year of growth is from one spring to the next. A fish spawned in the fall of 1944, if captured in the summer or fall of 1951, would be six years old since it has experienced seven springs or six completed years of growth.

#### Food Studies

Whole stomachs were preserved in 10 per cent formalin for later food item identification. Organisms were identified and

classified under three main categories; namely, planktonic, benthic, and miscellaneous.

No effort was made to do individual quantitative stomach analyses, the principal attention being directed towards qualitative analysis. The data were then expressed quantitatively for the sample as percentages. These percentages were obtained by expressing the number of occurrences of an item over the total number of stomachs containing food items.

During the investigation, 1028 whitefish stomachs were examined by the author. Of these, 40 were obtained from fish caught in Lake Onaman, 55 from whitefish caught in Lake Muskeg, 353 from whitefish taken from Shakespeare Island Lake, 371 from fish of the Sample Area of Lake Nipigon, and 209 from whitefish of Lake Nipigon exclusive of the Sample Area.

### Parasitological Investigations

#### Examination of Fish

A procedure similar to that used by the Federal Department of Fisheries was followed in the examination of whitefish for Trianaenophorus cysts. The fish were first gutted, the viscera and body cavity being examined for cysts. Next, the head was removed and the nape of the neck pressed so as to squeeze to the surface any worms which might be present in the nape. The fish were then filleted by cutting both sides of the body away from the vertebral column. The ribs were removed next. Each fillet was cut systematically into small cross-sections a centimetre in thickness commencing

anteriorly and working posteriorly. The number of cysts observed during this operation was recorded.

### Terminology of Whitefish Infection

Both 'infestation' and 'infection' have been used in describing parasitism in coregonine fish by plerocercoids of Trienophorus crassus. Considerable confusion has resulted. An 'infestation' is a term which was applied originally to external parasites, whereas, 'infection' originally connoted invisible and internal agents. In the nineteenth century, parasitologists modified the use of the term 'infestation' to apply also to internal parasites which do not multiply within the host.

In recent times, parasitologists, recognizing the confused usage of these terms, have endeavoured to standardize their application. A committee on Terminology, appointed by the American Society of Parasitologists, (Hertiz, Taliaferro, and Schwartz, 1937) considered this among other semantic problems of the science, and recommended:

" 'Infest' and 'infestation' ought to revert to their original use in connection with external and in most cases visible agents...the terms 'infect' and 'infection' are properly applicable to wherever the parasite invades and establishes itself with the host...We fail to see any reason for continuing the use of the term 'infestation' as applied to internal parasites".

In accordance with these recommendations the terms 'infect' and 'infection' will be used by the author in describing Trienophorus parasitism.

### Measurement of Whitefish Parasitism

The number of parasites present in the host will be used as a measurement of the infection of the host. The number of cysts in a number of whitefish is, thus, the measure of infection.

There are several objections to stating parasitic infection in terms of the number of cysts per given weight, as currently used by the Fisheries Department. Weight can be expressed as round, dressed, or filleted weight, which, unless the basis is stated, leads to considerable confusion. Aside from the objection to inaccuracy, there is a biological objection. The weight statement gives no concept of individual infection, an important biological consideration.

Thus, it is the author's opinion that useful and accurate statements of infection must be based on the number of parasites per number of hosts rather than on the weight of the fish parasitized. Miller (1945b) calculates infection in terms of cysts per one hundred fish. As an infection index, this is a useful figure for comparative purposes. The author, however, prefers to use the mean cyst count per fish, which can also be used as a measure of population infection.

### OBSERVATIONS

#### Geographical Observations

#### Previous Work

Cronk (1932), Hart (1932), and Pritchard (1935) have described Shakespeare Island Lake in the course of their investigations

on the bottom fauna, fish population, and aquatic vegetation, respectively.

Lake Nipigon has been studied by a number of authors.

Adamstone and Harkness (1923) and Adamstone (1924) described the bottom fauna of the lake; Clemens (1923), the limnology; Dymond (1926), the fish fauna; Bigelow (1923) and MacKay (1951), the plankton.

#### Geography of the Lakes

Lake Onaman is located 35 miles northwest of Geraldton in the Nipigon-Onaman Crown Game Reserve, the exact location being latitude  $50^{\circ}$  N., and longitude  $87^{\circ} 30'$  W. It has an approximate area of 50 square miles and a shoreline approximately 125 miles in length. The lake is drained by the Onaman River into Lake Nipigon.

Lake Muskeg, located 56 miles northwest of Port Arthur, is smaller than Lake Onaman. Its area is about 18 square miles, and its shore-line perimeter about 25 miles. This lake, located at latitude  $49^{\circ}$  N. and longitude  $90^{\circ}$  W., is more southerly than Lake Onaman. The lake lies in the Lake Superior watershed.

Lake Onaman is a typical lake of the Canadian Shield. Its surrounding terrain consists of low rocky ridges covered with ever-green forest. Lake Muskeg lies in a shallow basin of alluvial deposits of sand and clay. A large area of muskeg and swamp surrounds the lake.

Islands break up the expanses of both lakes. The northern half of Lake Onaman is studded with islands, but the southern and

deeper half is open and clear. A chain of islands running from north to south divides Lake Muskeg into two areas of open water.

Shakespeare Island Lake or Teapot Lake, as it is known locally, is situated in the southeastern portion of Shakespeare Island, the largest island in the southern half of Lake Nipigon. This lake is a small, irregularly-shaped lake with an approximate area of 85 acres. Its maximum length is about three-quarters of a mile, and its shoreline is approximately two and one-half miles in length. This lake drains into Lake Nipigon and is fed by springs and surface seepage.

Clemens (1923) gives a good geographic description of Lake Nipigon. Since his report the construction of two dams on the Nipigon River and the diversion of the Ogoki River have resulted in an increase of approximately six feet in the water level of Lake

Nipigon. This increase has inundated several areas and increased the area of the lake.

#### Contributions to, and Drainage from, the Lakes

Lake Onaman is fed by nine small creeks, five of which were traced for a short distance. The largest of these is Paska Creek which drains Paska Lake, a small lake lying to the east of Lake Onaman. At its mouth the creek is two feet deep and about 20 feet wide. Of the four other creeks investigated, two have headwaters in small ponds near Lake Onaman, the other two have their sources in low swampy ground. The lake is drained by the Onaman River which is 34 miles long and which empties into Humboldt

Bay on Lake Nipigon. Three falls and ten rapids are to be found along the course of the river which drops 300 feet between Lake Onaman and its mouth.

Kaogomok Creek is the largest of the many creeks which drain into Lake Muskeg. It drains Ricestalk and Upper and Lower Kaogomok Lakes. At its mouth the creek is four to five feet deep and 20 to 30 feet wide. In the last two miles of its course it meanders through muskeg. Numerous other streams empty into Lake Muskeg but these are small local streams having their sources in the surrounding bogs and muskegs. A small creek with several rapids and falls drains Lake Muskeg to the Dog River and thence to Dog Lake which is 196 feet lower in elevation than Lake Muskeg. Dog Lake drains via the Kaministiquia River into Lake Superior--a drop in elevation of 776 feet.

Shakespeare Island Lake is fed by one small stream of cold clear spring water. The lake drains into Lake Nipigon, which lies five feet below the level of the lake. The drainage is through a marshy slough. Cracked mud and scarcity of vegetation in a limited area near the mouth of the stream suggest that the spring freshet attains larger dimensions. In June, when the author first visited the lake, the stream was about one and a half feet wide and about six inches deep. It was obstructed in many places by tangled roots and plants. By August, however, the stream was practically dried up.

Lake Nipigon's watershed is approximately 6,000 square

miles in area. Recently this has been considerably increased by the

construction of the Ontario Hydro's Ogoki Water Diversion. There are more than 1,500 rivers and streams emptying into the lake.

Lake Nipigon is drained by the Nipigon River via Lake Helen into Nipigon Bay on Lake Superior. In this 60 mile water course there is a drop in elevation of 250 feet.

#### Character of Shore-line

Considerable differences are to be found in the shore-lines of the four lakes.

Lake Onaman's shore-line consists of a narrow strip of land completely covered by stones and boulders. From this shore-line the bottom drops off sharply to a depth of from four to six feet, and then slopes gently down to an average depth of 12 to 15 feet.

The shore of Lake Muskeg is characterized by sandy beaches. From the water-line the bottom slopes away gradually. As the depth of the water approaches three feet, the bottom changes from sand to muddy clay.

The shore-line of Shakespeare Island Lake is varied in nature. It is composed of sand and mud beaches, as well as, rocky slopes rising abruptly from the water's edge.

Lake Nipigon's shore-line is generally steep and rocky. However, the six-foot increase in the water level, mentioned above, has formed a new shore-line. Where the shore-line was formerly a sandy beach or a rocky shelf, it is now tree-lined.

### Depth of Lakes

Lake Onaman and Lake Muskeg are typical shallow northern lakes. The maximum depth observed in Lake Onaman was 25 feet; sounding in Lake Muskeg revealed a large depression with an average depth of 45 feet. Deep areas in Lake Onaman were restricted to three small depressions. The average depth of the greater portion of the lake was 15 feet. Large areas of Lake Muskeg gave soundings of six to seven fathoms, 36-42 feet.

For its small size, Shakespear Island Lake is a comparatively deep lake. The bottom slopes into a large basin in which the water has an average depth of 30 feet or more over the greater proportion of the lake's area. In the central part of this basin the deepest sounding obtained was 45 feet. Three small areas, at the head of bays, having a depth of less than six feet are to be found in the lake.

Little was learned of the underwater topography of the 136 square miles of Lake Nipigon which comprise the Sample Area. Clemens (1923) gives two soundings for the western side of the area, one, close in to Gros Cap, of 285 feet ( $47\frac{1}{2}$  fathoms), and the other between that point and the Anderson Islands of 264 feet (44 fathoms). Conversations with fishermen revealed the presence of a ditch running SW to NE between Shakespeare Island and the Anderson Islands. The fishermen report the centre of this ditch or trough as having a sounding of 44 fathoms (264 feet). The sides of this ditch consist of a series of banks with depths of water ranging from 15

to 35 fathoms over a distance of one to two miles. Along these banks the fishermen set their nets for whitefish and ciscoes.

### Limnological Observations

#### Temperature

Temperature readings showed the usual seasonal fluctuations for all lakes. At Lake Onaman, readings in early June showed the bottom temperatures to range from  $8^{\circ}\text{C}$ . to  $10^{\circ}\text{C}$ . while surface readings averaged from  $12^{\circ}\text{C}$ . to  $14^{\circ}\text{C}$ . On July 15, bottom readings of  $15.4^{\circ}\text{C}$ . to  $16.4^{\circ}\text{C}$ . and surface readings of  $18.5^{\circ}\text{C}$ . to  $19.5^{\circ}\text{C}$ . were taken. Temperatures in Lake Muskeg were higher as the readings were taken later in the summer. Surface temperatures ranged from  $19^{\circ}\text{C}$ . to  $21.5^{\circ}\text{C}$ . over most areas of the lake, but a high of  $23.2^{\circ}\text{C}$ . was recorded at one station on August 5th. Bottom temperatures at seven fathoms ranged from  $16.1^{\circ}\text{C}$ . to  $17.5^{\circ}\text{C}$ . Thermal stratification was not apparent at Lake Onaman, but a thermocline was located at the 17-19 foot level in Lake Muskeg on August 10th.

Shakespeare Island Lake showed typical thermal stratification. June readings showed surface temperatures averaging  $21.4^{\circ}\text{C}$ . and bottom temperatures averaging  $4.5^{\circ}\text{C}$ . with the thermocline at about 8 feet. On July 31st, readings showed that the surface temperature was  $21.9^{\circ}\text{C}$ . but that the bottom temperature had remained at  $4.5^{\circ}\text{C}$ . The thermocline was then at the 12-foot level. Towards the end of August, the surface temperature had fallen to  $19.9^{\circ}\text{C}$ .; the bottom temperature was  $4.7^{\circ}\text{C}$ ., and the thermocline

had dropped approximately another three feet to the 15-foot level.

### Hydrogen-Ion Concentration

Similar pH readings were obtained for Lakes Onaman, Muskeg, and Shakespeare Island. Although a number of readings were made at each lake, only slight variations in the pH of the particular lake being investigated were found. A surface pH range from 7.2 to 7.4 characterized the three lakes, but the pH was found to vary with depth. Bottom readings for a depth of 45 feet at Lake Muskeg were 6.7 units, whereas 6.2 units was the minimum reading obtained for the same depth in Shakespeare Island Lake. The minimum bottom reading for Lake Onaman was 7.2 units at a depth of 20 feet.

### Water Transparency

Several differences in water transparency were evident. Determinations with the aid of a Secchi disc gave a value of seven feet for both Lake Onaman and Lake Muskeg, although deeper readings were taken at times for Lake Onaman. The water of Lake Muskeg is darker brown than that of Lake Onaman, but rich phytoplankton in Lake Onaman served as an equalizing factor to give a similar reading to that of Lake Muskeg.

Secchi disc readings varied with the season in Shakespeare Island Lake. In June, the water transparency was recorded at 7.7 feet. On July 31st, it was recorded at 13.8 feet, and in August it was recorded at a depth of 12 feet. The water of Shakespeare Island Lake had a similar coloration to that of Lake Muskeg.

### Bottom Observations

Limited bottom observations indicated different types of bottom in each lake. Lake Onaman had a 'gyttja' layer of from three to six feet which was found to cover a large area of the bottom. On one occasion the nets were completely fouled with this benthic matter. A greater part of the deep water area in Lake Muskeg as well as a large area of the whole lake possessed a blue clay bottom containing phytoplankton. This layer measured from six to twelve inches in depth.

The bottom in Shakespeare Island Lake was hard sticky mud. In a few places sand was to be found, but these were along the shore-line.

### Plankton

Plankton samples for the purpose of identification were collected from Lake Onaman, Lake Muskeg, and Shakespeare Island Lake. As the plankton sampling was only of a qualitative nature, little if anything, can be said concerning the quantitative aspects.

A check list of the plankton organisms identified in the samples is given below. During the summer of 1950 collections were made in early and mid-July in Lake Onaman, and in late July and early August in Lake Muskeg. In Shakespeare Island Lake samples were taken in late June and in late August of 1951. The occurrence of the organisms is denoted by 'O' for Lake Onaman, 'M' for Lake Muskeg, and 'S' for Shakespeare Island Lake.

Check List of PlanktonPhytoplanktonCyanophyceae--Blue-green algae

|                                               |    |    |    |
|-----------------------------------------------|----|----|----|
| <u>Anabaena flos-aquae</u> (Lyngb?) Brebisson | 0. |    | S. |
| <u>Anabaena spiroides</u> Klebahn             |    | M. |    |
| <u>Aphanizomenon flos-aquae</u> (L.) Ralfs.   |    |    | S. |
| <u>Coelosphaerium</u> sp. Nägeli              | 0. | M. | S. |
| <u>Chroococcus</u> sp. Nägeli                 |    | M. |    |
| <u>Eucapsis</u> sp. Clements and Shantz       | 0. |    |    |
| <u>Gloeotrichia</u> sp. J. Agardh.            | 0. |    |    |
| <u>Gleocapsa</u> sp. Kützing                  |    |    | S. |
| <u>Microcystis</u> sp. Kützing                | 0. |    | S. |
| <u>Nostoc commune</u> Vaucher                 |    |    | S. |
| <u>Nodularia</u> sp. Mertens                  | 0. | M. |    |

Bacillariaceae--Diatoms

|                                             |    |    |    |
|---------------------------------------------|----|----|----|
| <u>Asterionella formosa</u> Hassall         | 0. | M. | S. |
| <u>Cyclotella</u> sp. Kützing               |    |    | S. |
| <u>Diatoma elongatum</u> Agardh.            | 0. | M. | S. |
| <u>Fragilaria crotonensis</u> Kitton        |    | M. | S. |
| <u>Fragilaria capucina</u> Desmaz           |    | M. |    |
| <u>Melosira granulata</u> (Ehr.) Ralfs.     |    | M. | S. |
| <u>Stephanodiscus</u> sp. Ehrenberg         |    | M. |    |
| <u>Synedra</u> sp. Ehrenberg                |    |    | S. |
| <u>Tabellaria fenestrata</u> Kützing        | 0. | M. | S. |
| <u>Tabellaria flocculosa</u> (Roth) Kützing |    | M. |    |

Chlorophyceae--Green algae

|                                                                  |    |    |    |
|------------------------------------------------------------------|----|----|----|
| <u>Arthrodesmus</u> sp. Ehrenberg                                | 0. |    |    |
| <u>Cosmarium</u> sp. Corda                                       |    |    | S. |
| <u>Dictyosphaerium</u> sp. Nägeli                                |    |    | S. |
| <u>Pediastrum</u> sp. Meyen                                      | 0. | M. |    |
| <u>Spondylosium</u> sp. Archer                                   | 0. |    |    |
| <u>Staurastrum</u> sp. Lundell                                   | 0. | M. |    |
| <u>Tetraedron trigonum</u> var. <u>gracile</u> (Reinsch) de Toni |    |    | S. |

Dinophyceae

|                                              |    |    |    |
|----------------------------------------------|----|----|----|
| <u>Ceratium hirundinella</u> (O.F.M.) Shrank | 0. | M. | S. |
|----------------------------------------------|----|----|----|

Chrysophyceae

|                                  |    |    |    |
|----------------------------------|----|----|----|
| <u>Dinobryon</u> sp. Ehrenberg   | 0. |    | S. |
| <u>Mallomonas caudata</u> Conrad |    | M. | S. |
| <u>Synura</u> sp. Ehrenberg      | 0. |    |    |

# Zooplankton

## Protozoa

Epistylis sp. Ehrenberg 0.

## Rotifera

Asplanchna sp. Gosse S.  
Conochilus unicorporis Rousselet M. S.  
Keratella (Anurea) cochlearis Gosse 0. M. S.  
Notholca longispina Kellicott 0. M. S.  
Polyarthra trigla Ehrenberg 0. M. S.  
Rattulus sp. Lamarck 0. S.  
Synchaeta sp. Ehrenberg 0. S.

## Copepoda

Cyclops bicuspidatus Claus 0. S.  
Cyclops sp. M.  
Diaptomus minutus Lilljeborg S.  
Diaptomus sp. 0. M. S.  
Nauplii 0. M. S.

## Cladocera

Daphnia longispina (O.F. Müller) 0. M. S.  
Bosmina sp. Baird 0. M. S.  
Holopedium gibberum Zaddach 0. S.

## Insecta

Chaoborus larvae S.

## Fisheries Investigations

### Species Occurrence

Table II lists the species of fish found in the four lakes investigated. Whitefish, Coregonus clupeaformis, and pike, Esox lucius, are common to the four lakes. Ciscoes, Leucichthys spp., were found only in Lake Muskeg and Lake Nipigon.

The cisco caught in Lake Muskeg was an atypical form which the author (1951) identified as a dwarf form of the species L. artedi.

Observations were made on the occurrence of hosts important to the life history of Triaenophorus nodulosus and T. stizostedionis. Perch, Perca flavescens, a possible intermediate host for T.

nodulosus, were caught in Lakes Onaman, Muskeg, and Shakespeare Island. Another host, burbot, Lota lota maculosa, frequently recorded as harbouring T. nodulosus, was taken in Lake Onaman.

Yellow pikeperch, Stizostedion vitreum vitreum, and trout perch, Percopsis omiscomaycus, the definitive and intermediate hosts respectively of T. stizostedionis were caught in Lake Onaman.

#### Commercial Fishing on the Lakes

Three of the lakes, Onaman, Muskeg, and Nipigon, are fished commercially. No commercial fishing is done on Shakespeare Island Lake as its small size renders this impracticable. Indeed, as far as the author can ascertain, there has been little or no fishing on this lake during the past 15 years.

The following summary, based on the records of five years of fishing ending with 1950, records the average annual production in pounds. A large poundage of pike is taken by the sport fishery in Lake Nipigon.

| <u>Lake</u> | <u>Whitefish</u> | <u>Pike</u> | <u>Ciscoes</u> | <u>Others</u> | <u>Total</u> |
|-------------|------------------|-------------|----------------|---------------|--------------|
| Nipigon     | 444,307          | 5,827       | 26,621         | 214,066       | 690,821      |
| Onaman      | 37,547           | 7,668       | ----           | 7,232         | 52,447       |
| Muskeg      | 8,991            | 2,683       | ----           | ----          | 11,674       |

Table II. Species of fish found in four lakes investigated.

| Species                       | Lake Onaman | Lake Muskeg | Shakespeare Island Lake | Lake Nipigon Sample Area | Other Areas |
|-------------------------------|-------------|-------------|-------------------------|--------------------------|-------------|
| <u>Acipenser fulvescens</u>   | -           | -           | -                       | -                        | X           |
| <u>Prosopium cylindraceum</u> | -           | -           | -                       | -                        | X           |
| <u>Coregonus clupeaformis</u> | X           | X           | X                       | X                        | X           |
| <u>Leucichthys artedi</u>     | -           | X           | -                       | -                        | -           |
| <u>L. nipigon</u>             | -           | -           | -                       | -                        | X           |
| <u>L. reighardi</u>           | -           | -           | -                       | X                        | X           |
| <u>L. zenithicus</u>          | -           | -           | -                       | X                        | X           |
| <u>L. hoyi</u>                | -           | -           | -                       | X                        | X           |
| <u>L. nigripinnis</u>         | -           | -           | -                       | X                        | X           |
| <u>Salvelinus fontinalis</u>  | -           | -           | -                       | -                        | X           |
| <u>Cristivomer namaycush</u>  | -           | -           | -                       | X                        | X           |
| <u>Catostomus commersonii</u> | X           | X           | -                       | X                        | X           |
| <u>Catostomus catostomus</u>  | -           | -           | -                       | X                        | X           |
| <u>Moxostoma aureolum</u>     | X           | -           | -                       | -                        | X           |
| <u>Moxostoma anisurum</u>     | X           | -           | -                       | -                        | -           |
| <u>Notropis heterolepis</u>   | -           | X           | X                       | -                        | X           |
| <u>Notropis hudsonius</u>     | X           | X           | X                       | -                        | X           |
| <u>Esox lucius</u>            | X           | X           | X                       | -                        | X           |
| <u>Percopsis omiscomaycus</u> | X           | X           | -                       | -                        | -           |
| <u>Perca flavescens</u>       | X           | X           | X                       | -                        | X           |
| <u>Stizostedion vitreum</u>   | X           | -           | -                       | -                        | X           |
| <u>Stizostedion canadense</u> | -           | -           | -                       | -                        | X           |
| <u>Percina caprodes</u>       | -           | -           | -                       | -                        | X           |
| <u>Poecilichthys exilis</u>   | -           | X           | X                       | -                        | -           |
| <u>Lucania inconstans</u>     | X           | X           | -                       | -                        | X           |
| <u>Lota lota maculosa</u>     | X           | -           | -                       | X                        | X           |
| No. of species                | 11          | 10          | 6                       | 9                        | 22          |

Table III. Relative catch of fish in the lakes investigated. (Relative number (Rel. no.) is the number estimated per 100 gill-net-nights).

| Species                       | Lake Onaman  |          | Lake Muskeg  |          | Shakespeare Island Lake |          | Sample Area Lake Nipigon |          |
|-------------------------------|--------------|----------|--------------|----------|-------------------------|----------|--------------------------|----------|
|                               | Actual catch | Rel. no. | Actual catch | Rel. no. | Actual catch            | Rel. no. | Actual catch             | Rel. no. |
| <u>Coregonus clupeaformis</u> | 219          | 348      | 389          | 393      | 494                     | 408      | 70                       | 109      |
| <u>Leucichthys</u> spp.       | -            | -        | 55           | 56       | -                       | -        | 1752                     | 2740     |
| <u>Esox lucius</u>            | 49           | 78       | 337          | 344      | 8                       | 7        | -                        | -        |
| <u>Catostomus commersoni</u>  | 238          | 378      | 280          | 286      | -                       | -        | 6                        | 9        |
| <u>Moxostoma aureolum</u>     | 5            | 8        | -            | -        | -                       | -        | -                        | -        |
| <u>Moxostoma anisurum</u>     | 4            | 6        | -            | -        | -                       | -        | -                        | -        |
| <u>Stizostedion vitreum</u>   | 700          | 1111     | -            | -        | -                       | -        | -                        | -        |
| <u>Perca flavescens</u>       | 64           | 98       | 110          | 111      | 1                       | 1        | -                        | -        |
| <u>Lota lota maculosa</u>     | 2            | 3        | -            | -        | -                       | -        | 71                       | 94       |
| Net nights                    | 63           | 100      | 93           | 100      | 121                     | 100      | 64                       | 100      |

### Relative Abundance of Certain Species

In an attempt to obtain a measure of the relative abundance of whitefish, pike, and ciscoes, the experimental net catches have been recalculated on the basis of 100 net nights. These figures are recorded in Table III.

It will be seen that for both Lake Onaman and Shakespeare Island Lake the number of whitefish is considerably greater than the number of pike. In Lake Muskeg the relative numbers of whitefish and pike are approximately equal. As no pike were taken in the Sample Area of Lake Nipigon, no comparison of the relative numbers of these two species can be made.

A comparison of the cisco-whitefish balance shows that for Lake Nipigon the ratio of ciscoes to whitefish is approximately 25:1; whereas, in Lake Muskeg the ratio is reversed. Whether the ratio is a close approximation of the actual ratio or not, there does appear significantly fewer ciscoes to whitefish in Lake Muskeg than in Lake Nipigon.

### Age Weight Relations

Age and weight are plotted for whitefish of the four lakes on Figure I. The weight plotted for each age is the mean weight of the whitefish within that particular age-class.

The growth curves indicate considerable differences in the rates of whitefish growth in the four lakes. Rapid growth is recorded for Lake Onaman whitefish, and for the whitefish of Lake Muskeg. This is particularly true for Lake Onaman. The curve for

Lake Nipigon shows a slower rate of growth than that indicated by the curves for the above two lakes. The growth curve for Shakespeare Island Lake suggests that these whitefish are stunted. In his study of whitefish growth Hart (1931) observes that Lake Nipigon whitefish grow more slowly than those of Lake Ontario, and that the whitefish of Shakespeare Island Lake are even slower in growth than those of Lake Nipigon. The curve obtained by the author for Lake Nipigon has a steeper slope than that obtained by Hart (ibid.); however, the curve for Shakespeare Island Lake is similar to that recorded by Hart.

#### Whitefish Food

In Table IV, length and food-item frequency are tabulated for Lake Onaman, Lake Muskeg, and Shakespeare Island Lake. Stomach contents were classified as either planktonic or benthic. This was done to decide if any change occurred in the plankton incidence in the diet as the whitefish increase in length. Original data with lists of food organisms used in compiling the above table are given in the Appendix.

Chaoborus larvae and pupae, and leeches were not included in either category because of their presence in both biotopes of the aquatic biome. Likewise, unidentified material was excluded from both of these categories.

It is evident in the Shakespeare Island data that there is a change in food habits with increasing length. The planktonic item percentage for each length interval decreases from 50 per cent

Table IV. Percentage of plankton and benthic items in whitefish food.  
(See Appendix for original data. Percentages are the ratio of the number of particular items of all items).

| Lake                    | Standard length in mms. of whitefish |     |     |     |     |     |     |     |     |
|-------------------------|--------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Classification of items | 100                                  | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 |
|                         | 149                                  | 199 | 249 | 299 | 349 | 399 | 449 | 499 | 549 |

#### Lake Onaman

|                             |   |   |   |      |      |      |      |      |      |
|-----------------------------|---|---|---|------|------|------|------|------|------|
| Planktonic                  | - | - | - | 12.5 | 13.3 | 11.6 | 9.1  | 23.7 | 9.1  |
| Benthic                     | - | - | - | 68.8 | 60.0 | 74.4 | 76.4 | 55.3 | 72.7 |
| No. of Stomachs cont'g food |   |   |   | 6    | 4    | 13   | 19   | 12   | 3    |

#### Lake Muskeg

|                             |       |      |      |      |      |      |       |   |   |
|-----------------------------|-------|------|------|------|------|------|-------|---|---|
| Planktonic                  | -     | 50.0 | 58.3 | 22.8 | 33.3 | 25.0 | -     | - | - |
| Benthic                     | 100.0 | 50.0 | 41.7 | 63.6 | 58.3 | 75.0 | 100.0 | - | - |
| No. of Stomachs cont'g food | 1     | 1    | 7    | 12   | 9    | 8    | 1     |   |   |

#### Shakespeare Island Lake

|                             |      |      |      |      |      |      |      |       |   |
|-----------------------------|------|------|------|------|------|------|------|-------|---|
| Planktonic                  | 50.0 | 51.2 | 13.5 | 3.0  | .3   | 2.4  | -    | -     | - |
| Benthic                     | 50.0 | 37.2 | 66.2 | 74.9 | 78.0 | 77.6 | 61.9 | 100.0 | - |
| No. of Stomachs cont'g food | 1    | 13   | 149  | 72   | 54   | 33   | 3    | 1     |   |

to 2.4 per cent. Fish of greater than 250 mm. length, six or more years of age, have practically no plankton in their diet, while those of shorter lengths have a considerable quantity. This more or less agrees with the observations of Hart (1931) who stated, "a considerable portion of plankton was taken by fish until their fifth year".

This decrease in plankton incidence is not so readily apparent in the Lake Muskeg data, although the percentage of plankton items of all items, shows a decrease from 50 per cent to 25 per cent. In Lake Onaman, the plankton item percentage remained small and relatively constant for all length groups. This feature coupled with the fact that the 250-299 mm. fish are generally two year old fish, suggests that there is little change in the food habits of whitefish with increasing length in this lake.

Another aspect of whitefish food habits is apparent in the following summary of data. In this case the total of planktonic items over the total of all items and the total of benthic items over the total of all items, both as percentages, are given for each of the three lakes.

| <u>Lakes</u>       | <u>Per cent Planktonic</u> | <u>Per cent benthic</u> |
|--------------------|----------------------------|-------------------------|
| Onaman             | 13.4                       | 69.1                    |
| Muskeg             | 31.7                       | 61.7                    |
| Shakespeare Island | 7.8                        | 71.3                    |

addendum: Manuscript Research Report No. 523--Factors affecting the infection of the whitefish, Coregonus clupeaformis (Mitchill), by the tapeworm, Triaenophorus crassus Forel, in the Thunder Bay district of Ontario-----by H.E. Welch.

line 2 of the legend in Fig. 1 should read "Lake Muskeg".

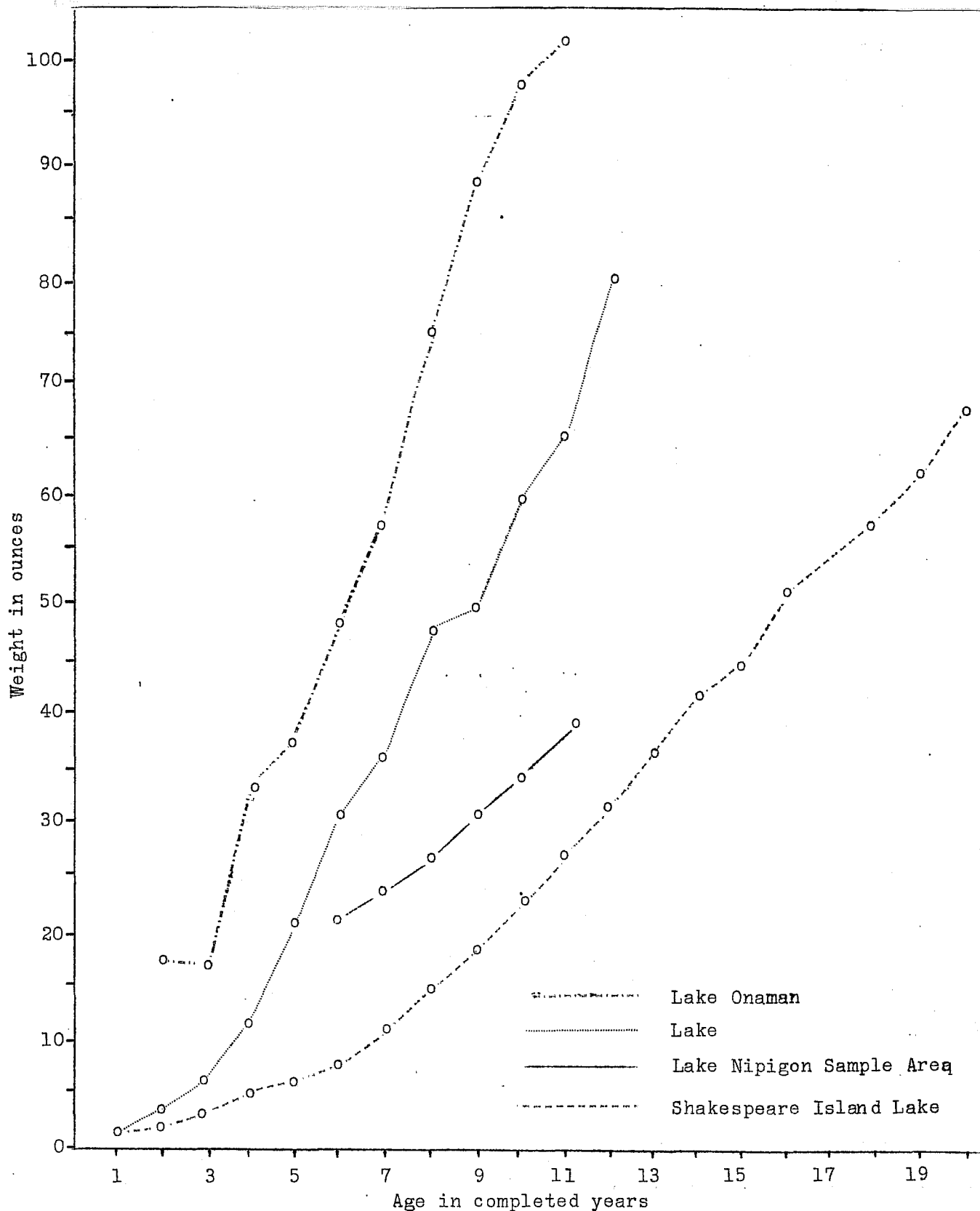


Figure 1. Growth curves for whitefish of four northern lakes. (See Table XIV for original data).

Table V. Stomach contents of whitefish, *C. clupeaformis* from the sample are of Lake Nipigon, 1951. (Food item occurrence is given as a percentage of all stomachs containing food).

| Date                            | June | July | August | Sept. |
|---------------------------------|------|------|--------|-------|
| No. of stomachs examined        | 85   | 96   | 92     | 98    |
| No. of empty stomachs           | 27   | 10   | 8      | 22    |
| No. of stomachs containing food | 58   | 86   | 84     | 76    |
| Planktonic Items                |      |      |        |       |
| <i>Mysis relicta</i>            | 12   | 49   | 87     | 22    |
| Unidentified Cladocera          | -    | 8    | 1      | 1     |
| Benthic Items                   |      |      |        |       |
| Filamentous Algae               | 2    | 1    | -      | -     |
| Vegetation                      | 29   | 65   | 58     | 49    |
| <i>Pisidium</i> sp.             | 69   | 43   | 23     | 63    |
| <i>Heliosoma</i> sp.            | -    | 2    | 15     | -     |
| <i>Sphaerium</i> sp.            | -    | 3    | -      | -     |
| <i>Physa</i> sp.                | 3    | 1    | -      | -     |
| Cestodes                        | 2    | 1    | -      | -     |
| Trematodes                      | -    | 14   | 5      | 9     |
| <i>Pontoporeia</i> sp.          | 62   | 76   | 15     | 74    |
| Tricoptera                      | 2    | 1    | -      | -     |
| Odonata nymphs                  | 2    | -    | -      | -     |
| Adult Insects                   | 72   | 30   | 24     | 28    |
| Beetle larvae                   | 5    | -    | -      | -     |
| Chironomid larvae               | 84   | 84   | 75     | 79    |
| Chironomid pupae                | -    | -    | -      | 3     |
| Fish eggs                       | 78   | 35   | 4      | 3     |
| Stones                          | 3    | 36   | 83     | 59    |
| Unidentified material           | 2    | 16   | 2      | 14    |

Table VI. Stomach contents of whitefish, C. clupearformis, from 13 areas of Lake Nipigon for July, 1951. (Food item occurrence is given as a percentage of all stomachs containing food).

| Area No.                        | 1   | 2  | 4   | 7   | 8  | 9   | 10 | 11 | 12 | 13 | 14  | 15  | 17  |
|---------------------------------|-----|----|-----|-----|----|-----|----|----|----|----|-----|-----|-----|
| No. of stomachs examined        | 20  | 20 | 21  | 19  | 20 | 20  | 20 | 20 | 20 | 20 | 20  | 20  | 19  |
| No. of empty stomachs           | -   | 2  | 1   | 1   | 2  | 1   | 2  | 3  | 2  | 1  | -   | -   | 2   |
| No. of stomachs containing food | 20  | 18 | 20  | 18  | 18 | 19  | 18 | 17 | 18 | 19 | 20  | 20  | 17  |
| <b>Planktonic items</b>         |     |    |     |     |    |     |    |    |    |    |     |     |     |
| Free floating algae             | -   | -  | -   | -   | -  | -   | 6  | -  | -  | -  | -   | -   | -   |
| Copepods                        | -   | 6  | -   | -   | -  | -   | -  | -  | -  | -  | -   | -   | 6   |
| <u>Daphnia</u> sp.              | -   | -  | -   | -   | -  | -   | 11 | -  | -  | 5  | -   | -   | -   |
| <u>Mysis relicta</u>            | -   | 6  | 5   | 28  | 50 | 37  | 39 | 47 | 28 | 26 | 5   | 20  | 18  |
| Unidentified cladocera          | -   | -  | -   | -   | 11 | -   | -  | -  | -  | -  | -   | -   | -   |
| <b>Benthic items</b>            |     |    |     |     |    |     |    |    |    |    |     |     |     |
| Filamentous algae               | -   | -  | -   | -   | 6  | -   | -  | -  | 17 | -  | -   | -   | -   |
| Vegetation                      | 60  | 39 | 15  | 67  | 67 | 32  | 56 | 65 | 72 | 74 | 55  | 75  | 41  |
| <u>Pisidium</u> sp.             | 60  | 78 | 70  | 100 | 44 | 26  | 28 | 71 | 89 | 53 | 100 | 90  | 100 |
| <u>Heliosoma</u> sp.            | -   | -  | -   | -   | 6  | -   | 11 | -  | -  | 11 | -   | 15  | -   |
| <u>Amnicola</u> sp.             | -   | -  | -   | -   | -  | -   | -  | 6  | -  | -  | -   | -   | 18  |
| Cestodes                        | 5   | -  | -   | -   | 6  | -   | -  | -  | -  | 5  | -   | 5   | -   |
| Trematodes                      | 30  | 6  | 15  | 11  | 17 | 11  | 22 | 24 | 17 | 26 | 5   | 50  | 35  |
| <u>Pontoporeia</u> sp.          | 100 | 94 | 100 | 100 | 78 | 68  | 44 | 82 | 94 | 95 | 100 | 100 | 88  |
| Sialididae                      | -   | -  | -   | -   | -  | -   | -  | -  | -  | -  | 5   | 5   | -   |
| Adult insects                   | 45  | 61 | 40  | 44  | 33 | 26  | 11 | 35 | 61 | 74 | 55  | 70  | 12  |
| Chironomid larvae               | 100 | 94 | 100 | 100 | 83 | 100 | 50 | 94 | 83 | 95 | 90  | 95  | 100 |
| Chironomid pupae                | -   | -  | -   | -   | -  | -   | -  | -  | 11 | -  | 5   | 30  | 6   |
| Fish eggs                       | 75  | 56 | 75  | 50  | 33 | 58  | 11 | 71 | 61 | 63 | 80  | 40  | 41  |
| Stones                          | 35  | 61 | 45  | 11  | 33 | 53  | 33 | 29 | 28 | 37 | 50  | 40  | 47  |
| <u>Chaoborus</u> sp.            | -   | -  | -   | -   | -  | 5   | -  | -  | -  | -  | -   | -   | -   |
| Unidentified mat'l              | 5   | 44 | 5   | 11  | 17 | 11  | 28 | -  | 28 | 32 | 15  | 20  | -   |

For location of areas as numbered above, see map, page 56.

It is evident from these figures, that plankton has the largest incidence in the diet of Lake Muskeg whitefish and the least in the diet of the Shakespeare Island Lake whitefish.

Two aspects of the food problem have been treated above; namely, the period of time during which there is a high incidence of plankton in the diet. Whitefish in Shakespeare Island Lake have plankton in their diet for a longer portion of their life history (0 to 6 years) than whitefish in the other three lakes, although the actual ratio of plankton incidence to all items is least in this lake. Whitefish in Lake Onaman have little plankton in their diet during their life span. Lake Muskeg whitefish show a planktonic diet for the early part of their life span (0 to 3 years) and also have a high incidence of plankton in their diet.

#### Food of Lake Nipigon Whitefish

Whitefish food studies of the Sample Area and of the 13 areas investigated in this lake are given in Tables V and VI respectively. As all these fish were taken in commercial  $4\frac{1}{2}$ -inch stretched mesh nets, statements concerning stomach contents are only applicable to commercial sized fish.

The data in Table V show little difference in the stomach contents for the four summer months. Mysis relicta appears most abundant in August, and this probably reflects an abundance of this organism during that month. Likewise, there is no significant difference in the stomach contents of fish from the 13 areas of Lake Nipigon, Table VI.

It may be concluded from these tables that the commercial sized whitefish of Lake Nipigon had similar food habits during the summer of 1951.

#### Food of Pike

Table VII lists the items found in the stomachs of pike caught in Lakes Onaman and Muskeg. Stomach content analyses were also made on the nine pike caught in Shakespeare Island Lake.

Four of these stomachs were empty; two contained whitefish; one, a spot-tailed minnow; another, two perch; and the last, unidentified fish remains.

No whitefish were found in the stomachs of Lake Onaman pike; however, four were found in the stomachs of Lake Muskeg pike. Twenty-six ciscoes were found in the stomachs of pike caught in Lake Muskeg. This latter observation suggests greater predator pressure against ciscoes than against whitefish in this lake.

The number of whitefish found in pike stomachs, over the numbers of stomachs containing food items provides an index of the extent of whitefish-pike interaction. This expressed as a percentage is 40 per cent for Shakespeare Island Lake, and three per cent for Lake Muskeg. If the ciscoes are included with the whitefish, this gives a total of 22 per cent for Lake Muskeg. These percentages and considerations are only applicable to the summer months, the period in which the investigations were carried on.

The average and maximum fork lengths of whitefish consumed by pike in Shakespeare Island Lake are  $9 \frac{1}{16}$  inches and  $10 \frac{1}{8}$  inches

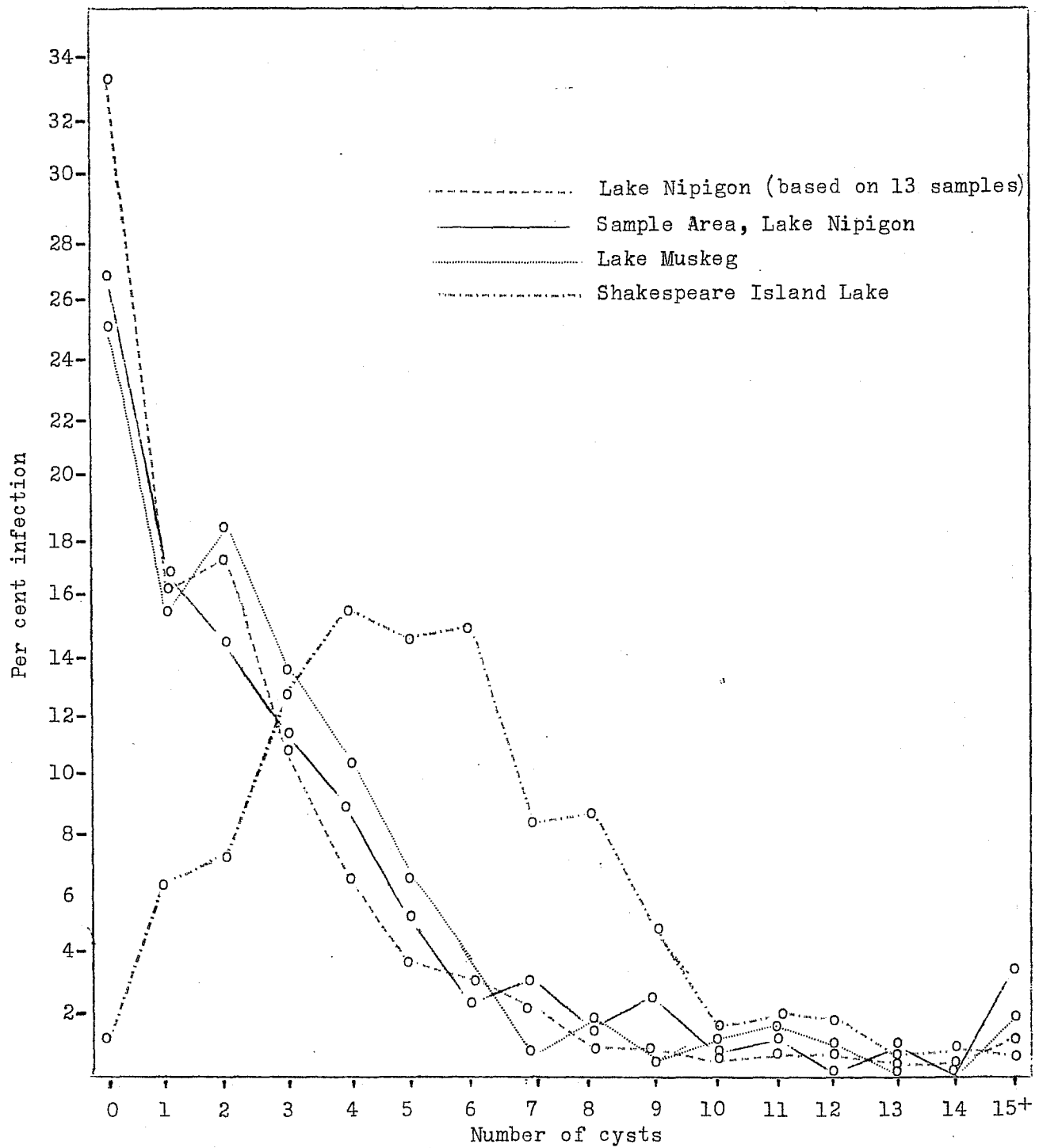


Figure 2. Infection in whitefish populations. (See Table XVIII for original data).

respectively; the same measurements for Lake Muskeg are 9½ inches and 11½ inches respectively. Presuming that predation is directed against these sizes and smaller, then fish of 0 to 8 years of age in Shakespeare Island Lake and of 0 to 4 years of age in Lake Muskeg are susceptible to predation. These ages were obtained from length-weight relations determined for each of the lakes.

Two phases of whitefish-pike interaction were investigated; namely, the amount and the duration. In Shakespeare Island Lake, not only the amount of fish, but also the number of age-classes accessible to predation (duration), is the largest of the three lakes investigated. In Lake Onaman where there is no evidence of predation, there must be little interaction between the species. Lake Muskeg with a moderate amount of interaction of from 0 to 4 years occupies an intermediate position between the extremes described for the other two lakes.

#### Parasitological Observations

##### Triaenophorus Occurrence

Plerocercoids of Triaenophorus crassus were found in whitefish, C. clupeaformis, of three of the four lakes investigated; namely, Lake Muskeg, Shakespeare Island Lake, and Lake Nipigon. Examination of Lake Onaman whitefish showed none to be infected with the parasite. The ciscoes, Leucichthys artedii, caught in Lake Muskeg had cysts present in their flesh. In Shakespeare Island Lake, no evidence of T. crassus infection was found in other species

Table VII. Stomach contents of pike.

|                                 | Lake Onaman |  | Lake Muskeg |  |
|---------------------------------|-------------|--|-------------|--|
| No. of stomachs examined        | 46          |  | 330         |  |
| No. of empty stomachs           | 20          |  | 196         |  |
| No. of stomachs containing food | 26          |  | 134         |  |

| Food item                     | Number | Per Cent | Number | Per Cent |
|-------------------------------|--------|----------|--------|----------|
| <u>Coregonus clupeaformis</u> | -      | -        | 4      | 3.0      |
| <u>Leucichthys</u> spp.       | -      | -        | 26     | 19.4     |
| <u>Catostomus commersoni</u>  | 4      | 15.4     | 8      | 6.0      |
| Minnow                        | -      | -        | 1      | .7       |
| <u>Esox lucius</u>            | -      | -        | 4      | 3.0      |
| <u>Percopsis omiscomaycus</u> | -      | -        | 4      | 3.0      |
| <u>Perca flavescens</u>       | 5      | 19.2     | 27     | 20.2     |
| <u>Stizostedion vitreum</u>   | 2      | 7.7      | -      | -        |
| <u>Eucalia inconstans</u>     | -      | -        | 4      | 3.0      |
| Unidentified fish remains     | 3      | 11.5     | 32     | 23.9     |
| Unidentified crustacea        | 2      | 7.7      | -      | -        |
| Odonata nymphs                | 7      | 26.9     | -      | -        |
| Insect larvae                 | -      | -        | 17     | 12.7     |
| Leeches                       | -      | -        | 2      | 1.5      |
| Unidentified remains          | 3      | 11.5     | 5      | 3.7      |

Discussion

The stomach contents of Stizostedion vitreum were found to be composed of a variety of fish species, including Coregonus clupeaformis, Leucichthys spp., Catostomus commersoni, Esox lucius, Percopsis omiscomaycus, Perca flavescens, Eucalia inconstans, and unidentified fish remains. The most common prey item was Perca flavescens, which constituted 20.2% of the diet. Other important prey items included Stizostedion vitreum (7.7%), Catostomus commersoni (15.4%), and Coregonus clupeaformis (3.0%). The diet of Stizostedion vitreum was found to be more varied than that of Coregonus clupeaformis, which primarily consumed Leucichthys spp. and Coregonus clupeaformis. The diet of Stizostedion vitreum was also found to be more varied than that of Catostomus commersoni, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of Esox lucius, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of Percopsis omiscomaycus, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of Perca flavescens, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of Eucalia inconstans, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the unidentified fish remains, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the unidentified crustacea, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the Odonata nymphs, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the insect larvae, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the leeches, which primarily consumed Coregonus clupeaformis and Leucichthys spp. The diet of Stizostedion vitreum was found to be more varied than that of the unidentified remains, which primarily consumed Coregonus clupeaformis and Leucichthys spp.

of fish; but, in Lake Nipigon, the following species of Leucichthys were found to be additional intermediate hosts of the parasite; viz., L. nigripinnis, L. hoyi, L. nipigon, L. zenithicus, and L. reighardi. Specimens of round whitefish, Prosopium cylindraceum and of lake trout, Cristivomer namaycush, from Lake Nipigon were examined also, but these were not found to be infected with the parasite.

Livers, collected by the author from Lake Muskeg perch and examined by Mr. G. H. Lawler of the Central Fisheries Research Board, were found to contain cysts of T. nodulosus.

#### Incidence of Infection

The incidence of infection was determined for each of the three lakes from the records of the number of cysts found in each fish. This was done in order to determine if differences existed in the incidence of infection of the populations and age-classes of these lakes.

#### Populations

An examination of the frequency polygons in Figure 2 reveals two types of distribution. In three cases, Lake Muskeg, Lake Nipigon Sample Area, and Lake Nipigon proper, there is a poisson-type distribution. In the fourth case, Shakespeare Island Lake, the distribution appears to be normal in nature. The poisson-type distributions are suggestive of lower probability values for the infection of whitefish in Lakes Muskeg and Nipigon. The three

distributions were tested, but none was found to be a true poisson series. This suggests that the chance of infection is not uniform throughout the distribution. Statistical analysis of the data is as follows:

| Lakes                   | All data |                 |      | Data minus uninfected fish |                 |      |
|-------------------------|----------|-----------------|------|----------------------------|-----------------|------|
|                         | N        | Mean $\pm$ S.E. | S.   | N                          | Mean $\pm$ S.E. | S.   |
| Lake Muskeg             | 313      | 2.35 $\pm$ .13  | 2.31 | 232                        | 3.17 $\pm$ .14  | 2.14 |
| Shakespeare Island Lake | 428      | 5.16 $\pm$ .13  | 2.64 | 422                        | 5.23 $\pm$ .13  | 2.59 |
| Sample Area             | 385      | 2.55 $\pm$ .14  | 2.84 | 276                        | 3.55 $\pm$ .17  | 2.77 |
| Lake Nipigon            | 1265     | 2.07 $\pm$ .07  | 2.48 | 830                        | 3.15 $\pm$ .09  | 2.44 |

#### Age Classes

The data from Lake Muskeg and Shakespeare Island Lake afford opportunities to investigate the distribution of cysts within a particular age-class of the population. Tables VIII and IX are tabulations of these data.

From these tables it can be seen that the age-class distribution of a similar nature to that of the population. It was anticipated that some age-classes of the Lake Muskeg population might show true poisson distributions as the whole population approached a poisson-like distribution. This, however, did not prove to be the case.

Table VIII. Age-cysts distribution in Lake Muskeg, 1950.

| Age in<br>years | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7 | 8 | 9 | 10<br>or more |
|-----------------|----|----|----|----|----|----|----|---|---|---|---------------|
| 1               | 8  | 2  | -  | 1  | -  | -  | -  | - | - | - | -             |
| 2               | 11 | 7  | -  | 1  | -  | -  | -  | - | - | - | -             |
| 3               | 14 | 10 | 10 | 6  | 3  | 3  | 1  | - | 1 | - | -             |
| 4               | 35 | 19 | 25 | 21 | 14 | 18 | 2  | 2 | 3 | 1 | 4             |
| 5               | 8  | 10 | 18 | 9  | 11 | 4  | 3  | - | - | - | 1             |
| 6               | 2  | 1  | 2  | 4  | 1  | 1  | 2  | - | 1 | - | 1             |
| 7               | -  | -  | 1  | -  | 2  | 4  | 1  | - | - | - | 2             |
| 8               | 1  | 1  | 1  | 1  | -  | 2  | -  | - | 1 | - | 1             |
| 9               | 1  | -  | 1  | -  | 1  | -  | 1  | - | - | - | 1             |
| 10              | -  | -  | 1  | -  | 1  | -  | -  | - | - | - | -             |
| 11              | -  | -  | -  | -  | -  | -  | -  | - | - | - | 2             |
| 12              | 1  | -  | -  | -  | -  | -  | -  | - | - | - | -             |
| Total           | 81 | 50 | 59 | 43 | 33 | 22 | 10 | 2 | 6 | 1 | 12            |

Table IX. Age-cysts distribution in Shakespeare Island Lake, 1951.

| Age in years | No. of cysts per fish |    |    |    |    |    |    |    |    |    | 10 or more |
|--------------|-----------------------|----|----|----|----|----|----|----|----|----|------------|
|              | 0                     | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |            |
| 1            | -                     | -  | 1  | -  | -  | -  | -  | 1  | -  | -  | -          |
| 2            | 1                     | 2  | 2  | 2  | 2  | 1  | 3  | -  | -  | -  | 1          |
| 3            | -                     | 2  | 1  | -  | 1  | 2  | 3  | -  | -  | -  | -          |
| 4            | 1                     | 3  | 2  | 2  | 6  | 3  | 2  | 3  | 2  | 2  | -          |
| 5            | 2                     | 6  | 5  | 14 | 22 | 15 | 14 | 6  | 7  | 2  | 3          |
| 6            | 1                     | 6  | 8  | 14 | 7  | 16 | 17 | 6  | 8  | 1  | -          |
| 7            | 1                     | 4  | 7  | 5  | 13 | 5  | 3  | 3  | 4  | 2  | 5          |
| 8            | -                     | 2  | 1  | 4  | 3  | 4  | 6  | 3  | 6  | -  | 3          |
| 9            | -                     | 1  | 1  | 6  | -  | 4  | 3  | 4  | 4  | 1  | 3          |
| 10           | -                     | -  | 2  | -  | 6  | 3  | 3  | 4  | 2  | 5  | 1          |
| 11           | -                     | 1  | 2  | 1  | 3  | 2  | 2  | 2  | 1  | 2  | 4          |
| 12           | -                     | -  | -  | 2  | -  | 2  | 2  | 1  | -  | -  | 3          |
| 13           | -                     | -  | -  | 1  | 1  | 1  | 3  | 2  | -  | 2  | 1          |
| 14           | -                     | -  | 1  | 1  | 1  | 1  | 2  | -  | 1  | 1  | -          |
| 15           | -                     | -  | -  | -  | 3  | 2  | -  | -  | 1  | -  | 1          |
| 16           | -                     | -  | -  | -  | -  | 1  | 2  | -  | -  | 1  | -          |
| 17           | -                     | -  | -  | -  | -  | -  | -  | -  | -  | -  | -          |
| 18           | -                     | -  | -  | 1  | -  | -  | -  | -  | -  | 1  | 1          |
| 19           | -                     | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -          |
| 20           | -                     | -  | -  | -  | -  | -  | -  | -  | -  | 1  | -          |
| Total        | 6                     | 27 | 31 | 53 | 68 | 63 | 65 | 35 | 36 | 21 | 26         |

### Factors Related to the Infection of Individuals

Various factors may influence the incidence of T. crassus infection in whitefish. Several of these were investigated and the observations on them are recorded below.

Age--To determine the relation between incidence of infection and age, it would be desirable to follow a year-class for a number of years and determine the infection for each year. This, however, has not been possible during the period of this investigation. Instead, the mean cyst count is determined for each age-class of the population. Figure 3 shows the age-infection relationship for the three lakes.

The three lakes show an increase in the mean cyst count with age up to a point, after which there is a decrease for the remaining years. This point occurs at age seven for both Lake Muskeg and Lake Nipigon. Not only the age at which the maximum cyst counts occur, but also the shape of the frequency distribution for Lake Nipigon is similar to that of Lake Muskeg, although the former is not as great in magnitude. In Shakespeare Island Lake, the incidence of infection is constant at about 4.4 cysts for age classes one to seven. Following this, there is a gradual rise to a maximum cyst count of 7.8 at age twelve, before the decrease occurs. The counts for 18 to 20 years have been disregarded because of the paucity of these age classes.

Weight--The mean cyst count was tabulated for four ounce intervals from the data of Lake Muskeg and Shakespeare Island Lake.

These are shown in Table X.

In both of these lakes the mean cyst count increases with increasing weight until at one interval, it ceases to increase and more or less remains constant, showing a tendency to decrease with increasing weight. Inadequate samples of heavier weight prohibit more accurate observations. In Lake Muskeg this point occurs at the 37-40 ounce interval; in Shakespeare Island Lake, it falls within the 25-28 ounce interval.

Sex--Two aspects were considered in the investigation of sex and infection. The first was the frequency of infection, and the second was the magnitude of infection.

The data from the samples of the 13 Lake Nipigon areas were used in this analysis. The samples included 1,284 individuals, 613 males and 667 females.

Degree of infection was investigated by the use of a two by two contingency table and tested by means of the Chi square.

No significant difference was found in the degree of infection of males and females.

In investigating the second feature, magnitude, a 't'

test was made on the mean cyst counts of males and females. The

probability was .42, indicating that the difference in the means,

2.38 for the males and 2.63 for the females, was a chance variation.

The conclusion from these observations is that, whatever ecological factors determine the infection of hosts, they must act equally upon the sexes.

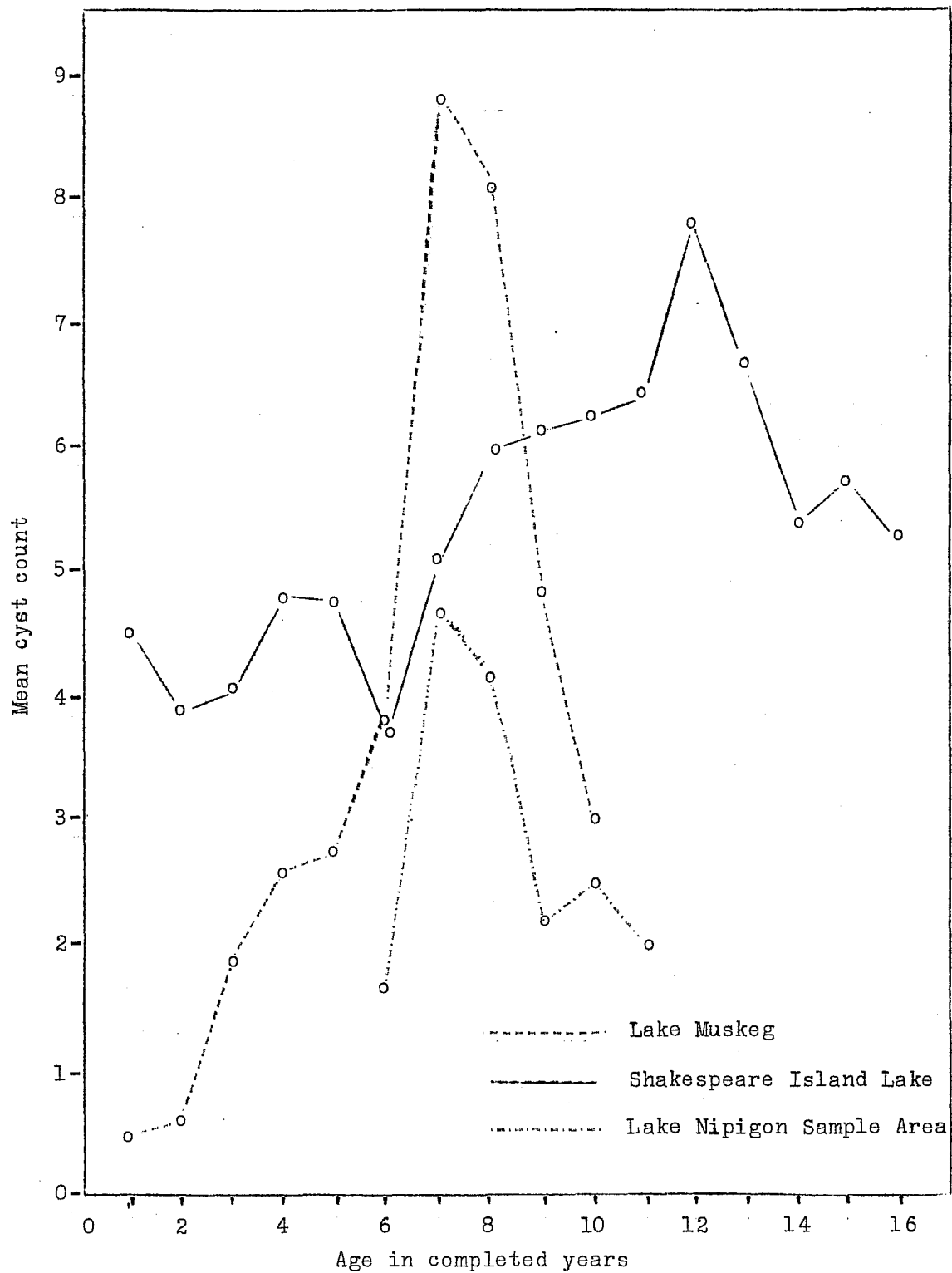


Figure 3. Age of host vs. mean cyst count in whitefish of three lakes. (See Table XIX for original data).

### Factors Related to the Infection of Populations

Locality--Mean cyst counts for 13 of the 17 areas of Lake Nipigon were plotted on a map. See Figure 4. The 13 samples used in obtaining these figures were taken by commercial fishermen during the second and third weeks of July. This was considered an adequate sampling of the commercial whitefish of Lake Nipigon as taken in 1951. The sampling period was short, almost simultaneous, and the sample localities sufficiently far apart to insure the obtaining of samples which were not duplications due to fish migration.

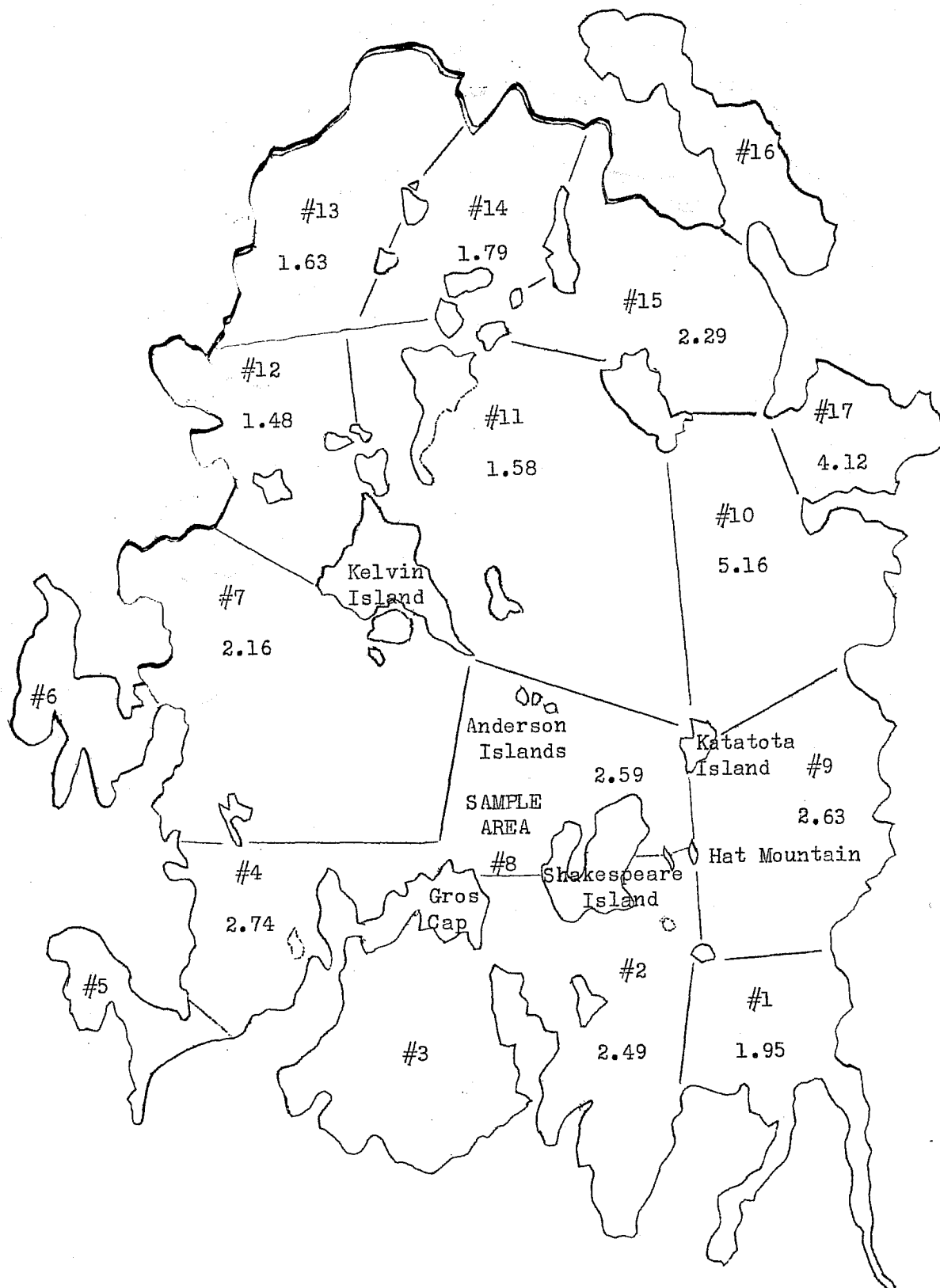
There is considerable variation in the mean cyst counts for the 13 localities, ranging from a low of 1.46 to a high of 5.16 cysts per fish. This observation agrees with that of Oakland (1949) who also recorded a variation of mean cyst counts for different localities in Lake Winnipeg.

A relation is found between mean cyst count and the nature of the water, either sheltered or open. The term 'sheltered' refers to such areas as bays, or open expanses broken by chains of island; open water designates expansive areas unbroken by either island chains or long points.

Generally, open areas have low mean cyst counts, while sheltered areas have high mean cyst counts. Examples of the former are areas #11, #12, #13, #14, and #15. Areas #7 and #8 are exceptions to this generalization. Examples of sheltered water areas with high cyst counts are areas #1, #2, and #4. As the

Table X. Weight of whitefish and mean cyst count. (Number in brackets is number of fish in sample).

| Weight interval (oz.) | Mean cyst count |                         |
|-----------------------|-----------------|-------------------------|
|                       | Lake Muskeg     | Shakespeare Island Lake |
| 1 - 4                 | .70 (30)        | 3.93 (27)               |
| 5 - 8                 | 1.95 (66)       | 4.81 (189)              |
| 9 - 12                | 2.24 (62)       | 4.52 (64)               |
| 13 - 16               | 2.88 (56)       | 5.79 (38)               |
| 17 - 20               | 2.48 (25)       | 6.07 (29)               |
| 21 - 24               | 3.50 (20)       | 5.89 (28)               |
| 25 - 28               | 2.40 (15)       | 6.93 (15)               |
| 29 - 32               | 7.90 (11)       | 6.30 (10)               |
| 33 - 36               | 3.43 (7)        | 6.82 (11)               |
| 37 - 40               | 8.71 (7)        | 6.00 (7)                |
| 41 - 44               | 5.00 (2)        | 5.00 (9)                |
| 45 - 48               | 7.66 (3)        | 7.00 (14)               |
| 49 - 52               | 2.28 (7)        | 7.00 (3)                |
| 53 - 56               | 8.00 (1)        | 5.00 (1)                |
| 57 - 60               | 3.00 (2)        | 8.00 (3)                |
| 61 - 64               | 18.00 (1)       | 5.00 (1)                |
| 65 - 68               | 11.00 (1)       | 9.00 (1)                |
| 77 - 80               | 0.00 (1)        |                         |



sample for #10, an open water area, was taken in shore water rather than in open water, it may be considered another example of a high mean cyst count in sheltered water.

Sheltered waters, broken as they are by islands and points, have more shallow water than open water. Thus, one of the differentiating features in high and low cyst counts may be depth.

Depth--The data provided by the 13 samples from Lake Nipigon provide material for a study of infection in terms of depth.

If the mean cyst count per fish, and the depth at which the samples were taken be listed so that the mean cyst count values are in descending order of magnitude, a relationship becomes apparent between infection and depth. See Table XI.

This table shows that, for the most part, there is a decrease in the number of cysts per fish with an increase in the depth of the water, or that infection varies inversely with depth.

The correlation coefficient for this relationship of mean cyst count and depth is  $-.72$ . A few exceptions are noticeable, particularly, the samples from Areas #2 and #17. There is some doubt as to the validity of the depths reported for these samples. A study of the map showed that the location in which a portion of the sample from Area #17 was taken in 15 fathoms deep, whereas a depth of 30 fathoms was reported by the fishermen.

Table XI. Depth and mean cyst count in Lake Nipigon, 1951.

| Area no. | Mean cyst count | Depth in fathoms |
|----------|-----------------|------------------|
| 10       | 5.16            | 15               |
| 17       | 4.12            | 15 (30)#         |
| 4        | 2.74            | 19 - 24          |
| 9        | 2.63            | 22               |
| 8        | 2.59            | 25 - 30          |
| 2        | 2.49            | 35 - 40          |
| 15       | 2.29            | 25               |
| 7        | 2.16            | 25 - 28          |
| 1        | 1.95            | 26 - 32          |
| 14       | 1.79            | 30 - 32          |
| 13       | 1.63            | 28 - 30          |
| 11       | 1.58            | 24 - 26          |
| 12       | 1.48            | 20 - 36          |

# (30)--This was the depth reported by the fishermen but the map showed the depth to be 15 fathoms.

Time--Four samples were taken from the Sample Area of Lake Nipigon during the summer of 1951. Mean cyst counts for the population and age-classes are given for June, July, August and September in Table XII.

An examination of this table reveals that the mean cyst count for the area ranged in magnitude during the summer from 2.6 to 5.8 cysts per fish. The conclusion to be drawn from these data is that the mean cyst count varies from month to month in the same locality. Oakland (1949) also describes variations in the mean cyst count with time for each of several localities in Lake Winnipeg. However, his variations are from year to year rather than from month to month.

Table XII. Mean cyst count of age-classes and sample times from the sample area of Lake Nipigon for the summer of 1951. (Number in brackets is number of fish in age-class).

| Age in years              | Date of sample |           |             |               | Mean cyst count for age-class |
|---------------------------|----------------|-----------|-------------|---------------|-------------------------------|
|                           | June 12th      | July 21st | August 11th | September 5th |                               |
| 6                         | 2.00 ( 1)      | -         | 1.86 ( 7)   | 1.40 ( 5)     | 1.69                          |
| 7                         | 3.54 (28)      | 1.43 ( 7) | 6.62 (37)   | 4.00 (33)     | 4.63                          |
| 8                         | 3.63 (59)      | 3.20 (56) | 6.15 (47)   | 4.00 (46)     | 4.16                          |
| 9                         | 1.33 ( 6)      | 2.06 (32) | 4.00 ( 4)   | 2.38 ( 8)     | 2.18                          |
| 10                        | 1.66 ( 3)      | 1.33 ( 3) | 2.00 ( 2)   | 3.67 ( 6)     | 2.50                          |
| 11                        | -              | 0.00 ( 2) | 4.00 ( 2)   | 2.00 ( 2)     | 2.00                          |
| Mean weight               | 26.1 oz.       | 29.5 oz.  | 25.6 oz.    | 26.9 oz.      |                               |
| Mean age                  | 7.8 yrs.       | 8.3 yrs.  | 7.6 yrs.    | 7.8 yrs.      |                               |
| Mean cyst count for month | 3.38           | 2.59      | 5.81        | 3.68          | 3.86                          |

If the differences between these figures are tested for statistical significance, only the mean cyst count of 5.8 is found to be significantly different from the others.

Pollution effect--A consideration of the high cyst count in the August sample introduces another factor. Four of the 99 fish contributed 255 cysts to the 575 cyst aggregate for August. As no fish of such heavy infection as these had been taken in either June or September's sampling, it seems a reasonable conclusion that these fish have migrated into the area. If these four fish are disregarded and the cyst count recalculated, the mean cyst count for August becomes 3.2, a figure similar to the mean cyst counts for June and September. Thus, a factor which may influence the infection of a population is the migration of heavily infected fish into a population of lighter infection. This may be termed 'a pollution effect'.

#### Evidence of Discrete Groups of Whitefish in Lake Nipigon

At the time of sampling in July, the fact that this sample was taken off the Anderson Islands, four miles distant from the locale in which the other three samples were secured, seemed of little significance. Later when the data were being compiled, the low cyst count for July attracted attention. Then, two other obvious differences were noticed; namely, a difference in the age-class composition and heavier mean weight of July's sample as compared with the other months. See Table XII. An examination of

the map revealed that this sample was taken on the opposite side of the deep ditch which lies between the Anderson Island and Shakespeare Island. These facts suggested that this sample may have been taken from a different group of fish than the other samples. Thus, the mean cyst count of 2.6 is the measure of the infection of a whitefish group off the Anderson Islands which may be discrete from that of the population off Abeki Point, Shakespeare Island.

These observations suggest two interesting points; namely, that more or less discrete groups of whitefish may exist in Lake Nipigon, and that each group has its own particular infection rate.

#### Time of Increment in the Parasitic Burden of Whitefish Populations

A review of Tables XII and XIII shows that there is an increase in the incidence of T. crassus in whitefish during the summer months. This increase may be designated the 'parasitic increment'.

August's mean cyst count is .42 greater than June's for Shakespeare Island Lake. In Lake Nipigon, September's count is .30 higher than that of June, while August's is 2.43 higher than June's and 2.13 higher than September's. July's has been disregarded for reasons discussed earlier. In Lake Muskeg, the mean cyst count of the fish caught in the first three days of the investigation (July 19th to 21st) was less than that of the fish

for the last three days of the investigation (August 7th to 9th). The mean cyst count based on 55 specimens for the first three days was 2.5 cysts; that of the last three days based on 83 specimens was 3.5, a difference of 1.0 cysts.

The above differences are not actually statistically significant, with the exception of the August count for Lake Nipigon. Nevertheless, the fact that there is the same kind of difference in three of the lakes, implies that the difference is a real one, and that a parasitic increment does occur during the summer. The times at which the data were collected give some clue as to the actual time of new cyst appearance in the flesh. Shakespeare Island Lake figures imply that the increment becomes observable some time in July and early August. Lake Nipigon data also imply July and early August, but Lake Muskeg's figures indicate late July.

Miller (1945b) recorded in his studies of tullibee infection in Lesser Slave Lake that "a new crop was acquired some time during late June or July".

This date is applicable also to the whitefish of the Thunder Bay District. As no increase in cysts is observable until late July and early August, the new infection must take place before late July.

#### Annual Increment to the Parasitic Burden

The actual size of the parasitic increment rather than the time of increment is important in this section. These increments were listed in the previous section.

The differences represent the average increase in the parasitic burden of the fish. It is an important value for its magnitude, positive or negative, determines the parasitic burden of the host.

Examination of Table XIII shows for Shakespeare Island Lake that the increase for each age-class may be positive or negative, and that it may vary considerable in magnitude. It is evident from the variable nature of these differences that there was no relation between age and the amount of the parasitic increment in the whitefish of this lake in 1951.

A close examination of the data in Table XII shows that there is no correlation between age and parasitic increment in whitefish for the Sample Area of Lake Nipigon.

#### Cyst Distribution in the Host

Figure 5 shows the percentage distribution of cysts in the musculature of whitefish from Shakespeare Island Lake and from Lake Nipigon. For this study the musculature was arbitrarily divided into the 14 regions shown in the diagrams.

These diagrams show that the greatest number of cysts, 40.7 per cent for whitefish of Shakespeare Island Lake and 49.4 per cent for whitefish of Lake Nipigon, were found in the epaxial musculature between the nape of the neck and the insertion of the dorsal fin.

Newton (1932) also found that the largest number of cysts was situated in this anterior region. A strict comparison cannot

Table XIII. The relation of mean cyst count to age in Shakespeare Island Lake whitefish for June and August.

| June 20 - 30 |             |              |                 | August 20 - 30 |              |                 |                    |
|--------------|-------------|--------------|-----------------|----------------|--------------|-----------------|--------------------|
| Age class    | No. of fish | No. of cysts | Mean cyst count | No. of fish    | No. of cysts | Mean cyst count | Increase Aug.-June |
| 1            | -           | -            | -               | 2              | 9            | 4.50            | -                  |
| 2            | 8           | 41           | 5.13            | 6              | 13           | 2.17            | - 2.96             |
| 3            | 5           | 22           | 4.40            | 4              | 14           | 3.50            | - .90              |
| 4            | 20          | 93           | 4.65            | 4              | 22           | 5.50            | + .85              |
| 5            | 78          | 364          | 4.67            | 18             | 91           | 5.06            | + .39              |
| 6            | 55          | 259          | 4.71            | 29             | 130          | 4.48            | - .23              |
| 7            | 33          | 155          | 4.70            | 19             | 106          | 5.58            | + .88              |
| 8            | 26          | 151          | 5.81            | 6              | 39           | 6.50            | + .69              |
| 9            | 16          | 90           | 5.63            | 11             | 75           | 6.82            | + 1.19             |
| 10           | 17          | 97           | 5.71            | 9              | 64           | 7.11            | + 1.40             |
| 11           | 11          | 71           | 6.45            | 9              | 57           | 6.33            | - .12              |
| 12           | 7           | 48           | 6.86            | 3              | 30           | 10.00           | + 3.14             |
| 13           | 8           | 53           | 6.63            | 3              | 20           | 6.67            | + .04              |
| 14           | 6           | 31           | 5.17            | 2              | 12           | 6.00            | + .83              |
| 15           | 4           | 22           | 5.50            | 3              | 18           | 6.00            | + .50              |
| 16           | 4           | 26           | 6.50            | -              | -            | -               | -                  |
| 17           | -           | -            | -               | -              | -            | -               | -                  |
| 18           | 1           | 3            | 3.00            | 2              | 21           | 10.50           | + 7.50             |
| 19           | -           | -            | -               | 1              | 5            | 5.00            | -                  |
| 20           | 1           | 9            | 9.00            | -              | -            | -               | -                  |

Average age 7.1 yrs. 7.4 yrs.

Total no. of fish 300 131

Total no. of cysts 1535 726

Average no. of cysts per fish 5.12 5.54

Average increase in no. of cysts per fish from June to August + .42

be made, as Newton divided the host into eight regions rather than fourteen. Contrary to Miller's findings (1945b) for tullibee, but in agreement with Newton (ibid.), cysts were found posterior to the anus.

More cysts were found on the right side of the host than on the left side. This difference was not statistically significant for Shakespeare Island Lake, although it approached the limit of significance. The data for the whitefish of Lake Nipigon and the data for a combination of the fish from both lakes show differences which are significant. Presumably, the high infection of whitefish in Shakespeare Island Lake obscures any tendency for cysts to occur on one side more than on the other.

Miller (1945b) has found a similar tendency in the distribution of cysts in the tullibee of Lesser Slave Lake.

As the greater number of cysts are found in the flesh of the right side of the body, it seems reasonable to assume that the greater number of procercoids enter the musculature from the stomach which in coregonine fishes lies along the right side of the body cavity against the right body wall.

#### DISCUSSION

Factors affecting infection of whitefish may be divided into physical and biological factors. Physical factors act through the non-living environment; biological factors act through the living environment.

### Physical Factors

A comparison of temperature, hydrogen-ion concentration, and water transparency of the four lakes revealed no significant differences correlated with the absence or presence of infection. Miller (1944) associates the absence of infection of whitefish in a lake in Alberta with high hydrogen-ion concentration. However, there is no evidence in this investigation for the association of infection and limnological character.

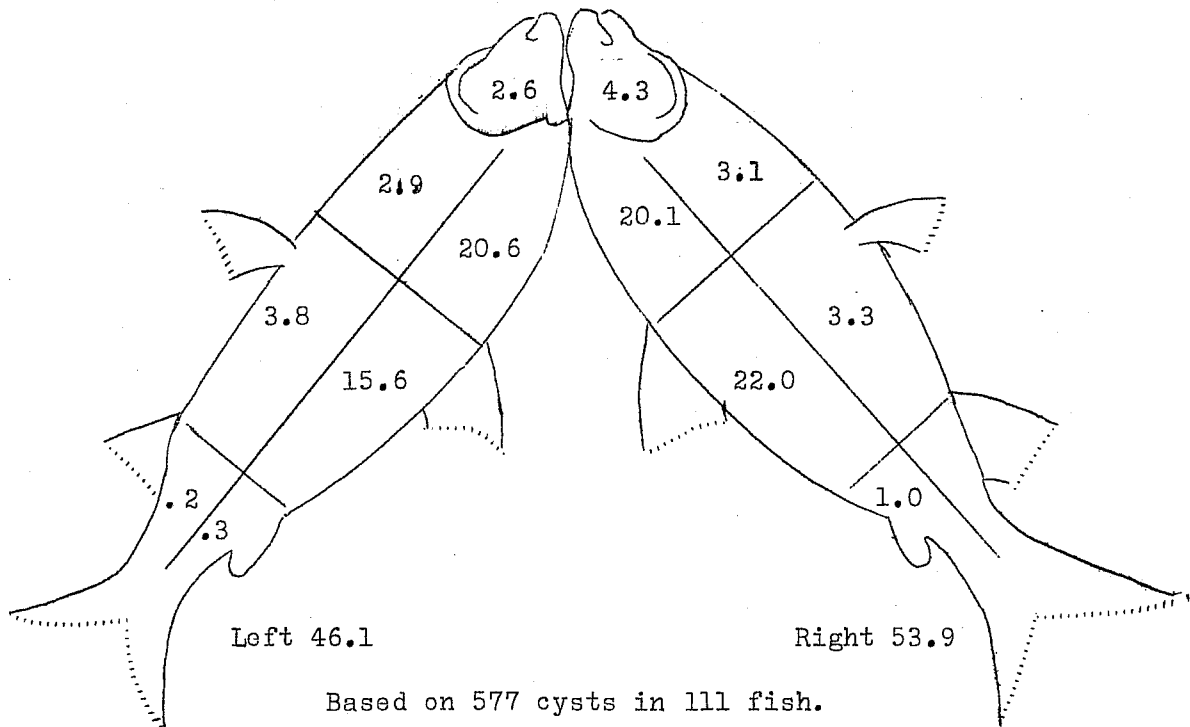
Depth and geographical position act indirectly, in that they probably prevent the occurrence of necessary host species.

Shallow depths may allow the heating of water to temperatures lethal to certain hosts, such as ciscoes, necessary to the parasite's life cycle. This may be one of the factors involved in the absence of ciscoes and infection in Lake Onaman.

Geographical position acts as a barrier to the immigration of infected species and the establishment of infection. Lake Onaman is closed to fish immigration; not only do falls on the Onaman River prevent the entrance of fish into the lake from waters lower in the watershed, but also no large body of water contributes to the lake. It is known that infected ciscoes spawn in the Onaman River, but the waterfalls prevent their entrance into Lake Onaman.

Waterfalls may also function as a drain of infected fish. If the lake were contaminated, pike moving downstream from the lake to spawning grounds would be effectively removed.

## Shakespeare Island Lake



## Lake Nipigon

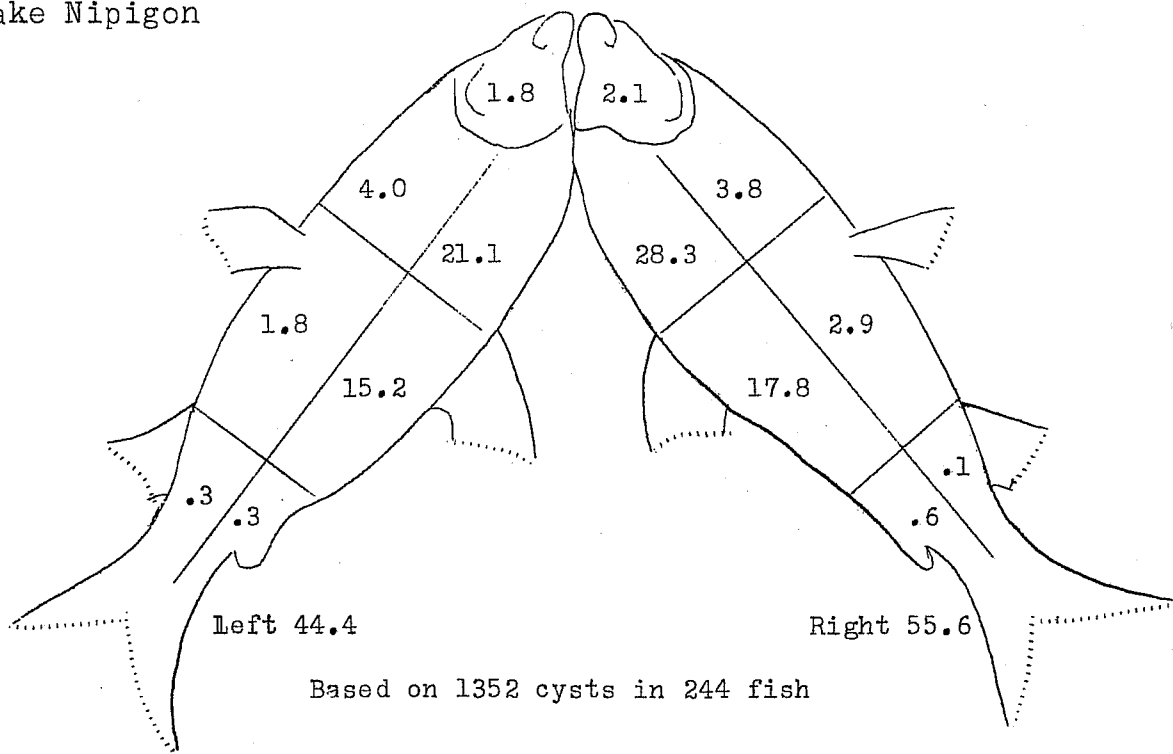


Figure 5. Percentage distribution of T. crassus cysts in the whitefish.

It is an interesting coincidence that three other lakes in the Thunder Bay District, Lakes Ara, Meta, and Marshall, are also free of infection and have a similar geographical position to that of Lake Onaman.

### Biological Factors

#### Infection of Individual Whitefish

The number of cysts in a fish may be considered as the product of a number of factors. The first may be called the immunological factor. This takes account of the fact that not all of the procercoids consumed will appear as plerocercoid cysts in the flesh owing to host resistance mechanisms.

The second may be termed the time factors. This takes account of the number of encounters that the host makes with the parasite in a given period of time whether the host is infected or not. In the tullibee, Miller (1945b) has shown that infection occurs annually. Presumably, this is also the case in whitefish, since the period of increment in whitefish coincides with that of ciscoes. Thus, cyst count is a function of the age of the host. This is true for the three infected lakes investigated. See Figure 3. Each curve shows a decrease in cyst count after a certain age, a fact suggesting that cysts disappear from the flesh of the fish. This implies that the cysts have a definite life span. Miller (1945b) has suggested a life span of four years for cysts in tullibee.

Table X shows that weight and infection are related.

As weight is a measurement of size, it follows that size is another factor determining infection. How these are related is difficult to explain. Perhaps, the relationship is manifest in the food habits of the fish as suggested by the following data which uses length as the measurement of size. In Shakespeare Island Lake, the whitefish have a pronounced planktonic diet until they attain a length of 200-249 mm. at approximately six years of age; in Lake Muskeg, the plankton diet is pronounced until the same length interval is reached, but this requires only four years of growth. Thus, the Shakespeare Island Lake whitefish are exposed to parasite infection through food habits for a longer period of time.

#### Infection of Populations of Whitefish

Two distinct types of cyst distribution in whitefish populations are shown in Figure 2; namely, a binomial for Shakespeare Island Lake, and a poisson-type for the other three localities. A question arises as to what causes these two types of distribution. Before any explanation can be given, further investigation will be required. Statistical analyses involving partial correlation of cysts and frequency, cysts and weight, and cysts and age should be carried out before any hypotheses are formulated to explain the difference.

There is, however, one interesting point. In Shakespeare Island Lake only 1.4 per cent of the sample were not infected; in

Lake Muskeg 25.2 per cent were free of the parasite; in the Sample Area of Lake Nipigon the percentage of non-infected fish in the samples was 26.6 per cent; in Lake Nipigon as a whole 33.5 per cent of the fish in the samples showed no infection. The fish of Shakespeare Island must have had more contact with the proceroid than those of the other locales. If the uninfected fish of Lake Muskeg, the Sample Area, and Lake Nipigon samples are disregarded, then the mean cyst counts advance and the shape of the frequency polygons become intermediate between their present form and the binomial distribution of cysts in the whitefish of Shakespeare Island Lake. A reasonable conclusion is that the amount of contact between the two intermediate hosts and the second definitive host is an important factor in determining the type of cyst distribution in a population of whitefish.

#### Infection of Small Populations

The term 'small population' will be used to describe the populations of Shakespeare Island Lake, of Lake Muskeg, and of groups recognized within the population of Lake Nipigon. The term 'large population' will be used to refer to that of Lake Nipigon.

The number of parasites which successfully complete the life cycle is important in the infection of whitefish populations. The successful completion of the life cycle might be considered to depend on the number of each host, relative to one another, present in a lake. This, however, does not appear to be the case. Infection shows no correlation with the ratio of the number of pike to the

number of whitefish. See Table III. For example, in Lake Onaman the ratio of pike to whitefish is small and infection is absent. In Shakespeare Island Lake the ratio tends to be even smaller, but infection is present and heavy in nature.

A better explanation lies in a consideration of the size of the environment in relation to the number of individuals present. This may be spoken of as host density. In Shakespeare Island Lake, a small lake, overpopulated by whitefish--a fact attested by their stunted growth--the small pike population has a chance to produce a comparable, if not greater, number of interactions with the whitefish than are produced in the larger-sized Lake Muskeg between a relatively large pike population and the whitefish. Thus, host density and infection may be correlated.

The previous paragraph may be considered a discussion of host interaction. Indeed it is, but host interaction involves other factors in this study; notably, the feeding of whitefish on Cyclops, a constituent of plankton, and the predation of pike upon whitefish. The amount of interaction may be assessed by examining the data on whitefish food habits and pike predation. In Shakespeare Island Lake, the plankton food habit extends over the longest period of time when compared with the other lakes. When the actual percentages of plankton in the diet of the whitefish are compared, Shakespeare Island Lake has paradoxically the lowest percentage. The explanation of this paradox seems to be that, whereas, the Shakespeare Island Lake plankton percentage is

the lowest, the plankton food habit continues for the longest period of time. This, undoubtedly, compensates for the small percentage of plankton in the diet. Similarly, the pike predation on whitefish is of greater magnitude and longer duration in Shakespeare Island Lake than in any of the other lakes. In general, Shakespeare Island Lake has the largest amount of interaction on the basis of these two characteristics. In Lake Onaman there is no evidence of the whitefish possessing a plankton diet, and of pike predation on whitefish. The conclusion is that there is little or no interaction of the hosts in Lake Onaman. Plankton feeding and predation in Lake Muskeg seem to be intermediate as compared with that found in the other lakes, and suggests a moderate amount of host interaction. These measures agree closely with the degree of infection for the lakes, Shakespeare Island Lake being high, Lake Muskeg being average, and Lake Onaman zero. Therefore, it may be concluded that there is a definite relation between host interaction and infection.

It was noted in the pike stomach analyses that the maximum lengths of whitefish consumed were  $11\frac{1}{2}$  inches and  $10\frac{1}{8}$  inches for Shakespeare Island Lake and Lake Muskeg respectively. Fish of these lengths are 14.8 ounces and 11 ounces weight and eight and four years old respectively. If two assumptions are made, first that whitefish of this and smaller sizes are subject to predation, and second that the experimental net catches are representative of the population, then by totalling the figures in Table XIV, it

is seen that 73 per cent of the fish in Shakespeare Island Lake and 71 per cent of the fish in Lake Muskeg are subject to predation. Thus a comparable percentage of the whitefish population is available for pike predation in each lake; however, in Shakespeare Island Lake, the predation of pike on whitefish amounted to 40 per cent and in Lake Muskeg, to three per cent.

Two facts could account for this difference; namely, the number of prey and the kind of prey available to the predator. The number of prey available does not seem important for in Lake Muskeg, there were relatively fewer ciscoes than whitefish available, yet seven times as many ciscoes were found in the pike stomachs. Presumably, the pike take more ciscoes than whitefish, even when the former are present in smaller number. Ciscoes occurred in 19 per cent of the stomachs as compared with the three per cent occurrence of whitefish. This suggests that a major portion of the parasites complete their life cycle through the cisco-pike link, and that, in this lake, whitefish are only accidental hosts. Thus, another factor in the infection of the whitefish population is the presence of other prey species for pike to prey upon in a lake.

The major factor in the infection of whitefish seems to be the amount of host interaction. This appears to be greatest in Shakespeare Island Lake, less in Lake Muskeg, and least in Lake Onaman, a feature directly correlated with the degree of infection of these lakes.

### Infection of Large Populations

Just as the characters of small populations are the integrations of the characteristics of individuals, so also are the characters of large populations the integrations of the characteristics of small populations, groups, or sub-populations!

In the discussion of the observations on locality the effect of sheltered and open water was studied and related to depth. A correlation was established between the degree of infection and depth, the shallower the water the greater the infection. This is readily explained by host interaction. The shallow shore populations of whitefish have greater contact with infected Cyclops and with pike. MacKay (1951) has observed that copepods are more abundant in shallow sheltered bays than in open water. Pike are more numerous in shallow shore water but as Dymond (1923) states, "Occasionally specimens are taken from water over 100 feet deep." Each group of whitefish, shallow or deep, experiences different environmental conditions, which presumably, in the case of shallow water fish, lead to greater infection.

In the parasitological observations the 'pollution effect' was observed. This term has been introduced to describe the effect of migrant members of heavily infected groups entering more lightly infected groups. These migrants presumably come from the shore groups in the course of seasonal migrations. This feature is of considerable importance from the commercial fishing standpoint, where a few heavily parasitized fish may ruin a whole catch for

export by increasing its cyst content beyond the limit permitted by export and import regulations.

#### SUMMARY AND CONCLUSIONS

1. During the summer of 1950 and 1951, investigations on the infection of whitefish by T. crassus were carried out on four lakes of northwestern Ontario; namely, Lake Onaman, Lake Muskeg, Shakespeare Island Lake, and Lake Nipigon. The geographical and limnological characters of the lakes were examined and the biometrics and the parasitism of the whitefish population of each lake studied.

2. There appears to be a relationship between geographic location and infection. Headwater lakes, drained by rivers having falls or long rapids which act as barriers to the entry of infected fish, are usually free of infection.

3. A brief resume of the pertinent facts is presented regarding the life history of the whitefish, the life cycle of T. crassus, and the fisheries management programmes designed for the control of the parasite in whitefish.

4. Depth, temperature, hydrogen-ion concentration, and water transparency were examined for three of the lakes. A list of the planktonic organisms of the lakes was prepared.

No relation was found between the infection of whitefish and the limnological characters of temperature, hydrogen-ion concentration, and water transparency.

5. The number of fish examined was 6,534, of which 2,852 were whitefish. Studies were made of the relative abundance of species, and the growth and food of whitefish for each lake. Food studies were based on an examination of 1,082 whitefish stomachs.

6. Analyses of infection for each population of whitefish were made in relation to age, weight, and sex.

Infection was found to increase with age during the first seven years in Lake Muskeg and during the first twelve years in Shakespeare Island Lake, after which, infection decreases.

Infection increases with weight until the fish attains a weight of one and three quarters to two pounds, following which infection remains more or less constant in relation to weight.

The changes in the relation of age and weight to infection infer that cysts disintegrate in the flesh and thus have a definite life span.

There was no statistically significant difference in the infection of the sexes.

7. The relations of locality, depth, and times of sampling to infection were also analysed.

The nature of the locality is related to the degree of infection. Whitefish taken in open water have less infection than those taken in sheltered areas.

There is an inverse relationship between infection and the depth of water at which a sample is taken.

A relation exists between the degree of infection of whitefish and the time of sampling. Samples taken from the same water at the end of the summer showed heavier infection than those taken earlier in the summer.

An increment in the parasitic burden of whitefish with T. crassus occurs during late June or July.

8. Cyst distribution within the host was also investigated. The significantly greater number of cysts found in the musculature of the right side, and the occurrence of the stomach to the right of the mid-line suggest that proceroids emerge from the stomach.

9. Factors affecting the infection of whitefish were classified as physical and biological. More attention was given to the biological factors which were treated at the individual, the small or homogeneous population, and the large or heterogeneous levels.

Grouse of whitefish within a large or heterogeneous population, such as that of Lake Nipigon, have their own distinct infection rates.

10. There appears to be no correlation between the infection of whitefish by Triaenophorus and the ratio of the number of pike to the number of whitefish present in a lake.

Two types of cyst distribution are to be found in populations, each more or less dependent on the relative amount of host interaction. This, in turn, depends on the host density--the number of whitefish and pike per unit volume of water.

Factors which affect the amount of infection are the extent to which whitefish are planktonic in food habits, and the extent to which pike feed on the intermediate host.

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APPENDIX

Table XIV. Relation of age and weight for whitefish from four lakes. (Number in brackets is number of fish in sample).

| Age in years | Mean weight in ounces |             |                         |                          |
|--------------|-----------------------|-------------|-------------------------|--------------------------|
|              | Lake Onaman           | Lake Muskeg | Shakespeare Island Lake | Sample Area Lake Nipigon |
| 1            | -                     | 1.5 (17)    | 1.5 (2)                 | -                        |
| 2            | 17.3 (3)              | 3.5 (32)    | 2.4 (14)                | -                        |
| 3            | 17.0 (5)              | 6.7 (68)    | 3.7 (9)                 | -                        |
| 4            | 33.6 (3)              | 11.8 (165)  | 5.4 (25)                | -                        |
| 5            | 38.1 (19)             | 20.8 (68)   | 6.7 (100)               | -                        |
| 6            | 48.6 (27)             | 30.7 (17)   | 8.0 (84)                | 20.8 (13)                |
| 7            | 58.0 (58)             | 36.4 (11)   | 11.0 (52)               | 23.5 (104)               |
| 8            | 75.6 (49)             | 47.8 (10)   | 14.8 (32)               | 26.8 (207)               |
| 9            | 89.2 (24)             | 49.8 (5)    | 18.8 (26)               | 30.9 (50)                |
| 10           | 98.2 (9)              | 60.0 (2)    | 22.7 (26)               | 34.1 (14)                |
| 11           | 102.6 (9)             | 65.5 (2)    | 27.0 (20)               | 39.2 (6)                 |
| 12           | 121.0 (4)             | 80.0 (1)    | 31.9 (10)               | -                        |
| 13           | 119.0 (1)             | -           | 36.7 (11)               | -                        |
| 14           | -                     | -           | 41.4 (8)                | -                        |
| 15           | -                     | -           | 44.4 (7)                | -                        |
| 16           | -                     | -           | 51.3 (4)                | -                        |
| 17           | -                     | -           | -                       | -                        |
| 18           | -                     | -           | 57.7 (3)                | -                        |
| 19           | -                     | -           | 62.0 (1)                | -                        |
| 20           | -                     | -           | 68.0 (1)                | -                        |

Table XV. Occurrence of food items to fish lengths for whitefish of Lake Onaman. (Figures are percentages obtained by expressing the number of stomachs containing the item of the number of stomachs containing food).

| Standard length interval<br>in mm.       | 250  | 300  | 350  | 400  | 450  | 500  |
|------------------------------------------|------|------|------|------|------|------|
|                                          | 299  | 349  | 399  | 449  | 499  | 549  |
| No. of stomach examined                  | 6    | 4    | 16   | 21   | 18   | 3    |
| No. of empty stomachs                    | -    | -    | 3    | 2    | 6    | -    |
| No. of stomachs<br>containing food items | 6    | 4    | 13   | 19   | 12   | 3    |
| <b>Planktonic items</b>                  |      |      |      |      |      |      |
| Copepods                                 | -    | -    | -    | -    | 16.7 | -    |
| <u>Holopedium gibberum</u>               | -    | -    | 15.3 | 5.3  | 25.0 | 33.3 |
| <u>Daphnia</u> sp.                       | 16.7 | -    | 7.7  | 15.8 | 8.3  | -    |
| Cladocera winter eggs                    | -    | 25.0 | -    | -    | 16.7 | -    |
| Gyrinidae                                | -    | 25.0 | 7.7  | -    | 8.3  | -    |
| Hydrophilidae                            | 16.7 | -    | 7.7  | 5.3  | -    | -    |
| <b>Benthic items</b>                     |      |      |      |      |      |      |
| Vegetation                               | -    | -    | 15.3 | 10.5 | -    | -    |
| Nemerteans                               | -    | -    | 15.3 | -    | -    | -    |
| <u>Amnicola</u> sp.                      | 16.7 | 25.0 | 30.8 | 36.9 | 25.0 | 33.3 |
| <u>Pisidium</u> sp.                      | 16.7 | 50.0 | 38.5 | 21.1 | 33.3 | 33.3 |
| <u>Planorbis</u> sp.                     | -    | -    | -    | 5.3  | -    | 66.7 |
| Unid. Amphipoda                          | -    | 25.0 | -    | -    | -    | -    |
| <u>Hyallolela</u>                        | -    | -    | -    | -    | -    | -    |
| <u>knickerbocheri</u>                    | 33.3 | 50.0 | 53.9 | 57.9 | 50.0 | 33.3 |
| Hydracarina                              | 33.3 | 25.0 | 23.1 | 31.6 | 16.7 | -    |
| Odonata nymphs                           | -    | -    | -    | -    | -    | 33.3 |
| Caddis fly larvae                        | 16.7 | 25.0 | 38.5 | 21.1 | 16.7 | 66.7 |
| Insect parts                             | 66.7 | 25.0 | 7.7  | 10.5 | 33.3 | -    |
| Chironomid larvae                        | -    | -    | 23.1 | 26.3 | -    | -    |
| <u>Chaoborus</u> sp. larvae              | 33.3 | 50.0 | 15.3 | 5.3  | 25.0 | -    |
| Leeches                                  | -    | 25.0 | 23.1 | 5.3  | 33.3 | -    |
| Unidentified material                    | 16.7 | 25.0 | 7.7  | 31.6 | 8.3  | 66.7 |

Table XVI. Occurrence of food items to fish lengths for whitefish of Lake Muskeg. (Figures are percentages obtained by expressing the number of stomachs containing the item of the number of stomachs containing food).

| Standard length interval<br>in mm.       | 100   | 150   | 200   | 250  | 300  | 350  | 400   |
|------------------------------------------|-------|-------|-------|------|------|------|-------|
|                                          | 149   | 199   | 249   | 299  | 349  | 399  | 449   |
| No. of stomachs examined                 | 1     | 1     | 10    | 18   | 20   | 14   | 1     |
| No. of empty stomachs                    | -     | -     | 3     | 6    | 11   | 6    | -     |
| No. of stomachs<br>containing food items | 1     | 1     | 7     | 12   | 9    | 8    | 1     |
| Planktonic items                         |       |       |       |      |      |      |       |
| Daphnia sp.                              | -     | 100.0 | 100.0 | 41.5 | 44.4 | 25.0 | -     |
| Benthic items                            |       |       |       |      |      |      |       |
| Pisidium sp.                             | -     | -     | 42.9  | 8.3  | -    | -    | 100.0 |
| Unidentified<br>amphipoda                | -     | -     | -     | -    | -    | -    | 100.0 |
| Hydracarina                              | -     | -     | -     | 8.3  | -    | -    | -     |
| Mayfly larvae                            | 100.0 | 100.0 | -     | 41.5 | 11.1 | 25.0 | -     |
| Insects                                  | -     | -     | -     | 16.6 | 33.3 | 12.5 | -     |
| Chironomid larvae                        | -     | -     | 28.6  | 33.3 | 22.2 | 37.5 | 100.0 |
| Chironomid pupae                         | -     | -     | -     | -    | 11.1 | -    | -     |
| Caddisfly larvae                         | -     | -     | -     | 8.3  | -    | -    | -     |
| Unidentified material                    | -     | 8.5   | -     | 25.0 | 11.1 | -    | -     |

Table XVII. Occurrence of food items to fish lengths for whitefish of Shakespeare Island Lake. (Figures are percentages obtained by expressing the number of stomachs containing the item of the number of stomachs containing food).

| Standard length                | 100   | 150  | 200  | 250  | 300  | 350  | 400   | 450   |
|--------------------------------|-------|------|------|------|------|------|-------|-------|
|                                | 149   | 199  | 249  | 299  | 349  | 399  | 449   | 499   |
| No. of stom. exam'd.           | 1     | 16   | 160  | 75   | 55   | 35   | 3     | 1     |
| No. of empty stom.             | -     | 3    | 11   | 3    | 1    | 2    | -     | -     |
| No. of stom. cont'g food items | 1     | 13   | 149  | 72   | 54   | 33   | 3     | 1     |
| Planktonic items               |       |      |      |      |      |      |       |       |
| Free floating algae            | -     | 7.7  | 5.4  | -    | -    | 3.0  | -     | -     |
| Copepods                       | -     | 7.7  | 2.0  | -    | -    | 3.0  | -     | -     |
| <u>H. gibberum</u>             | -     | 53.9 | 6.7  | -    | -    | 3.0  | -     | -     |
| <u>Daphnia</u> sp.             | 100.0 | 76.9 | 32.8 | 12.5 | 1.9  | 3.0  | -     | -     |
| <u>Bosmina</u> sp.             | -     | -    | 1.3  | -    | -    | -    | -     | -     |
| <u>Polyphemus</u> sp.          | -     | 23.1 | 2.0  | -    | -    | -    | -     | -     |
| Dytiscid beetles               | -     | -    | 3.4  | 2.8  | -    | 3.0  | -     | -     |
| Benthic items                  |       |      |      |      |      |      |       |       |
| Filamentous algae              | -     | -    | 2.7  | 11.1 | 16.6 | 18.2 | 66.7  | -     |
| Vegetation                     | -     | 23.1 | 13.4 | 63.7 | 72.2 | 87.9 | 100.0 | -     |
| <u>Gordius</u> sp.             | -     | -    | 2.0  | 5.6  | 1.9  | 6.1  | -     | -     |
| <u>Pisidium</u> sp.            | -     | -    | 9.4  | 11.1 | 16.6 | 24.2 | 33.3  | -     |
| <u>Pontoporeia hoyi</u>        | -     | -    | 6.0  | 16.6 | 22.2 | 45.5 | 33.3  | -     |
| Hydracarina                    | 100.0 | 15.3 | 36.9 | 38.9 | 37.0 | 48.5 | -     | -     |
| Caddis fly larvae              | -     | -    | -    | 1.4  | 7.4  | 9.1  | -     | 100.0 |
| Insects                        | -     | 30.8 | 79.1 | 69.4 | 68.5 | 51.5 | 33.3  | -     |
| Chironomid larvae              | -     | 23.1 | 56.4 | 86.1 | 76.0 | 78.8 | 66.7  | -     |
| Chironomid pupae               | -     | 15.3 | 37.6 | 33.3 | 37.0 | 42.4 | -     | -     |
| Beetle larvae                  | -     | -    | 4.7  | 4.2  | 3.7  | 9.1  | -     | -     |
| Fish eggs                      | -     | -    | -    | 1.4  | 9.3  | 6.1  | -     | -     |
| Stones                         | -     | 15.3 | 15.4 | 38.9 | 59.2 | 57.6 | 100.0 | -     |
| <u>Chaoborus</u> sp. larvae    | -     | 30.8 | 49.0 | 68.1 | 66.7 | 66.7 | 100.0 | -     |
| <u>Chaoborus</u> sp. pupae     | -     | 7.7  | 21.5 | 36.1 | 35.1 | 33.3 | 100.0 | -     |
| Unidentified material          | -     | -    | 10.0 | 9.7  | 16.7 | 24.2 | 66.7  | -     |

Table XVIII. Percentage occurrence of cysts for four localities.

| No. of<br>cysts | Lake<br>Muskeg |     | Shakespeare<br>Island Lake |     | Lake Nipigon<br>Sample Area |     | Lake Proper |      |
|-----------------|----------------|-----|----------------------------|-----|-----------------------------|-----|-------------|------|
|                 | Per<br>Cent    | No. | Per<br>Cent                | No. | Per<br>Cent                 | No. | Per<br>Cent | No.  |
| 0               | 25.4           | 81  | 1.4                        | 6   | 27.2                        | 109 | 33.8        | 435  |
| 1               | 15.7           | 50  | 6.3                        | 27  | 17.0                        | 68  | 16.5        | 212  |
| 2               | 18.6           | 59  | 7.2                        | 31  | 14.5                        | 58  | 17.5        | 225  |
| 3               | 13.5           | 43  | 12.3                       | 53  | 11.3                        | 45  | 11.0        | 142  |
| 4               | 10.3           | 33  | 15.8                       | 68  | 9.0                         | 36  | 6.6         | 85   |
| 5               | 6.9            | 22  | 14.6                       | 63  | 5.3                         | 21  | 3.7         | 48   |
| 6               | 3.1            | 10  | 15.1                       | 65  | 2.2                         | 9   | 3.1         | 40   |
| 7               | .6             | 2   | 8.1                        | 35  | 2.8                         | 11  | 2.3         | 29   |
| 8               | 1.9            | 6   | 8.4                        | 36  | 1.8                         | 7   | 1.0         | 13   |
| 9               | .3             | 1   | 4.9                        | 21  | 2.2                         | 9   | .9          | 12   |
| 10              | .3             | 1   | 1.6                        | 7   | .5                          | 2   | .3          | 4    |
| 11              | 1.2            | 4   | 1.9                        | 8   | 1.0                         | 4   | .5          | 6    |
| 12              | .3             | 1   | .9                         | 4   | .5                          | 2   | .5          | 6    |
| 13              |                |     | .2                         | 1   |                             |     | .2          | 3    |
| 14              |                |     | .4                         | 2   | 1.0                         | 4   | .1          | 1    |
| 15              |                |     |                            |     |                             |     |             |      |
| and more        | 1.9            | 6   | .9                         | 4   | 3.7                         | 15  | 2.0         | 26   |
| Total           | 100.0          | 319 | 100.0                      | 431 | 100.0                       | 400 | 100.0       | 1287 |

Table XIX. Mean cyst count for age-classes. (Number in brackets is number of fish in sample).

| Age                            | Lake Muskeg | Shakespeare<br>Island Lake | Lake Nipigon<br>Sample Area |
|--------------------------------|-------------|----------------------------|-----------------------------|
| 1                              | .45 (11)    | 4.50 ( 2)                  | -                           |
| 2                              | .53 (19)    | 3.86 (14)                  | -                           |
| 3                              | 1.85 (48)   | 4.00 ( 9)                  | -                           |
| 4                              | 2.57 (134)  | 4.79 (24)                  | -                           |
| 5                              | 2.70 (64)   | 4.74 (96)                  | -                           |
| 6                              | 3.80 (15)   | 3.68 (84)                  | 1.69 (13)                   |
| 7                              | 8.80 (10)   | 5.02 (52)                  | 4.63 (105)                  |
| 8                              | 8.13 ( 8)   | 5.94 (32)                  | 4.16 (208)                  |
| 9                              | 4.80 ( 5)   | 6.11 (27)                  | 2.18 (50)                   |
| 10                             | 3.00 ( 2)   | 6.23 (26)                  | 2.50 (14)                   |
| 11                             | 14.50 ( 2)  | 6.40 (20)                  | 2.00 ( 6)                   |
| 12                             | 0.00 ( 1)   | 7.80 (10)                  | -                           |
| 13                             | -           | 6.64 (11)                  | -                           |
| 14                             | -           | 5.38 ( 8)                  | -                           |
| 15                             | -           | 5.71 ( 7)                  | -                           |
| 16                             | -           | 5.25 ( 4)                  | -                           |
| 17                             | -           | -                          | -                           |
| 18                             | -           | 8.00 ( 3)                  | -                           |
| 19                             | -           | 5.00 ( 1)                  | -                           |
| 20                             | -           | 9.00 ( 1)                  | -                           |
| Average                        | 2.10        | 5.25                       | 3.86                        |
| No. of white-<br>fish examined | 319         | 431                        | 396                         |