A SURVEY OF THE ENTOMOSTRACA OF MANITOBA

AND

A STUDY OF FEEDING OF LAKE WINNIPEG CISCOES

By I. Gilbert Arnason

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INTRODUCTION

The scientific value of a survey of the *Entomostraca* of Manitoba was first suggested to the author as a worthy undertaking, and as a suitable subject for a Ph. D. thesis, by Dr. J. A. McLeod under whose direction this work was begun over five years ago. The years intervening have been spent in the examination of samples of plankton collected from nearly 80 lakes from various parts of Manitoba. Samples from over 100 ponds, ditches and sloughs, and from 20 rivers and creeks have also been studied. Collections from so many sources and from such an extensive area could never have been made by one worker and the assembling of all these collections for study by the author represents an example of scientific teamwork which should be heartening to all scientific workers and reflects great credit on the agencies involved. The chief agencies for collection of plankton samples were: The Game and Fisheries Branch, Department of Mines and Natural Resources, Province of Manitoba; and the Central Fisheries Research Station, Fisheries Research Board of Canada, Winnipeg, Manitoba. During the years 1941-1947, plankton samples were collected for the Game and Fisheries Branch, Province of Manitoba, by Dr. J. A. McLeod and/or D.R. Moir, and subsequently by other field parties under the direction of G. E. Butler. Collections made included dredge samples, vertical lifts, horizontal drags usually at the surface and at 12-15 feet, and littoral collections along the shore and among water plants. Collections made by these agencies were supplemented by extensive collections made by the present worker.

The importance of a survey of the Entomostraca of Manitoba (Parts I, II and III of this thesis) may be dealt with under three headings:

(1) Entomostraca as links in food chains and especially as food of fishes.

(2) Entomostraca as intermediate hosts of parasitic organisms.

(3) The value of a survey of the Entomostraca of Manitoba as a contribution to general scientific knowledge.

ENTOMOSTRACA AS LINKS IN FOOD CHAINS AND ESPECIALLY AS FOOD OF FISHES

It is quite impossible in the space that can be devoted to this topic to deal adequately with it. All that can be done is to briefly outline representative studies that have been made by a few of many competent scientific workers.

Mann (1917) so well expresses some of the fundamental relationships existing in food chains that I have taken the liberty of quoting in full the following paragraph: "The diatom is the smallest of all the green, chlorophyll-bearing plants; but despite its insignificant size, these lilliputian workers are so numerous that the sum total of their activity is almost beyond calculation. Professor Kofoid has estimated that the average number of diatoms in 1 cubic meter of water in the Illinois River is 35,558,462. Thriving abundantly in all the waters of the earth, fresh and salt, from the north pole to the south, the countless myriads of these plants are turning the substances held in solution in the waters of the streams, lakes and seas into living material and are doing this in that strange alembic where it always takes place, namely, the green, chlorophyll-grain. By harnessing in some way a sunbeam to its machinery it turns out from the crude material of mineral matter the vital material of plant tissue, and on this plant tissue there feeds directly or indirectly most of the animal life of the sea. Some of the minuter forms of economic value to mankind, like the smaller fishes (for example, the sardine) and the shellfish (clams and oysters) make these plants their principal if not their exclusive food. The teeming swarms of tiny animal creatures, of which the copepods may be cited as an example, are the links between the diatoms and those other organisms which in turn prey upon them".

The Importance of Entomostraca as Links in Feed Chains

Lowe (1936) made observations on some Pacific diatoms as the food of Copepoda and fishes. He listed the following food chains:

Chart of Food Chains

Fish	Feed, 1st degree	Feed, 2nd degree	Feed, nth degree
Spring salmon	Herring	Copepoda	Diatoms
Ling Cod	Herring	Copepoda	Diatoms
Rockfish	Herring	Copepoda	Diatoms
Dogfish	Herring	Copepoda	Diatoms

Chart of Food Chains

Fish	Feed, 1st degree	Feed, 2nd degree	Feed, nth degree
Adult Herring	Crustacea		
Flounder	Mollusca		
Lemon Sole	Mollusca		

Similar observations were made by Lebour (1918, 1925) at Plymouth, England, upon the herring Clupea harengus L. and the sprat Clupea sprattus L. Lebour found that the young herring and the young sprat, in the postlarval stage, fed upon diatoms, larval molluscs, and small copepods, and, further, that the young mollusca and copepods fed upon diatoms and the flagellated green alga, Halosphaera viridis. Mann (1921) examined the stomach contents of some hake and found them gorged with small herring; the herring in turn were filled with copepods and the copepods with diatoms. The concluding remark of his observations was: "No diatoms, no hake".

Forbes (1883) shows that many of the larger predaceous species of fishes feed on smaller fishes, which, in turn, feed very largely on entomostracans, the percentage of Entomostraca in the animal food taken by Eucalia inconstans being 50%, by Pungitius pungitius 40%, by Abramis chrysoleucas 15%, by Notropis heterodon 56%, and by Notropis atherinoides 19%. The same author (1883) states that from experimental evidence the first food of the common whitefish consists chiefly of two copepods Cyclops thomasi and Diaptomus sicilis. Ryder (1888) states that the sturgeon Acipenser sturio when one or two inches long feeds largely on microcrustaceans. Hankinson (1908) found that young of yellow perch feed entirely on Entomostraca while Needham (1909) states that young Eupmotis gibbosus two inches long had eaten chiefly copepods.

Hankison (1910) states that from the examination of the stomachs of fishes collected from shoals with much plant life, it appeared that midge larvae and entomostracans were the chief food of the smaller fishes--minnows, darters, and the young of perch, sunfish, black bass, rock bass, and catfish. The larger fishes were taking principally insect larvae and crayfish.

Reighard (1913) lists a specimen of Notropis cornutus as having 2/3 of the food-mass cladocerans, and a young N. hudsonius as "filled with Cladocera". Pearse (1918) found that Entomostraca made up the following percentages by volume of the food of some fishes of Wisconsin:

Fish	Ostracoda	Cladocera	Copepoda
Catostomus commersonii	16.8	3.6	14.8
Eucalia inconstans	3.2	16.0	19.3
Notropis heterodon	.5	33.4	11.0
Micropterus salmoides	.1	15.1	2.9
Cyrpinus carpio	7.0	3.6	10.4
Pimephales notatus	.3	25.1	2.6

Clemens and Bigelow (1922) after examining the alimentary canals of 211 ciscoes of several species state that "Daphnia formed the great bulk of the contents". Moore (1922) says that "the most important single item in the food of the smallmouth bass is waterfleas" and lists Cladocera as among the most important food of young Leucichthys osmeriformis, Ambloplites rupestris, and Notropis cayuga. Bigelow (1923) found that young Catostomus commersonii from 1.7 to 2.1 cm. in length fed chiefly on Daphnia, Bosmina, Alona and Copepoda. Clemens, Dymond and Bigelow (1924) showed that young whitefish, Coregonus quadrilateralis and C. clupeaformis feed chiefly on entomostracans, as do the young of the pike perch Stizostedion vitreum, and the adults of the spot-tailed minnow, Notropis hudsonius.

Brooker Klugh (1929) states that from observations in the field in many habitats he is inclined to believe that the chief food of dragonfly nymphs consists of entomostracans.

Forbes (1880) notes the variation in food habits of the common perch with age. He states that the common perch has a food history of three periods--the periods of infancy, youth, and mature age. In the first it lives wholly on Entomostraca and the minutest larvae of Diptera; in the second, commencing when the fish is about an inch and a half long, it takes up first the smaller and then the larger kinds of aquatic insects in gradually increasing ratio, the entomostracan food at the same time diminishing in importance; and in the third it appropriates, in addition, mollusks, crayfishes, and fishes--in the lake specimens depending almost wholly on the last two elements.

Pearse (1915) studied the food of small shore fishes in waters near Madison, Wisconsin. He found that some fish changed their food as they grew larger, while others stuck to one diet. Some ate the same food in all habitats while others varied their diet with varying environment. Different species of fish captured in the same habitats were found to have selected different kinds of food from the available supply.

Pearse noted three cases of change of food with increase in size. Of twenty Labidesthes sicculus collected at Station 1, the ten largest individuals (average length 41.2 mm.) had eaten 38.5% Cyclops and a trace of plants, whereas the ten smallest (average length 22.6 mm.) had eaten only 1.7% Cyclops and 44.4% algae and seeds. Lepomis pallidus as it grew larger consumed more Hyalella and less Cyclops. The smaller sticklebacks, Eucalia inconstans, ate more Chydorus sphaericus than larger individuals of the same species which had taken Cyclops instead.

In most species of fish which Pearse examined he found that there was considerable variation in feed with changes in environment. Perca flavescens, for example, ate 33% of dipterous larvae at Station 5; at Station 6, 57.7% Hyalella; and at Station 7, 96.2% Daphnia hyalina. Fundulus majalis menona was very variable in its food habits having eaten 55% Cladocera at Station 3; 35% Cladocera at Station 6; 63.8% Ostracoda at Station 8 (August); and 30.8% vegetation at Station 8 (September). Micropterus salmoides at different times fed largely on fish at one station (66%) and on dipterous larvae (57.7%) at another.

Turner and Kraatz (1920) studied the food of young large-mouth black bass in some Ohio waters. They found that up to 30 mm. in length the food consists almost entirely of Entomostraca and minute midge larvae. From 30 to 50 mm. in length Entomostraca become negligible in quantity and midge larvae diminish rapidly, while amphipods form the principle articale of diet, and larger insect larvae and fish are taken in small quantities. From 50 to 80 mm. in length the food consists principally of larger insect larvae and fish while Entomostraca, midge larvae and Amphipoda practically disappear from the diet.

Eddy and Surber (1947) report that the paddlefish (Polyodon spathula Walbaum) may attain a length of over 6 feet and a maximum weight of 185 pounds. They also state that these large fish feed chiefly on minute crustacea, which they secure by swimming with their mouths open. "The crustacea are strained from the water by means of long, fine gill-rakers, which form very efficient plankton nets. The stomachs examined by Eddy and Simer (1929) were usually filled with minute water fleas and copepods. Occasionally they may sweep up a few small aquatic insects." Eddy and Simer (1929) estimated the amount of water strained through the gills of a large paddlefish as between 62 cubic meters and 203 cubic meters to obtain enough Corethra larvae and Cyclops to fill a stomach with a capacity of 700 cc.

These and many other studies indicate the importance of Entomostraca as links in food chains. They also indicate that while *Entomostraca* are the basic food of nearly all fish in infancy or youth, they may continue to be the chief food utilized in some large fish, such as the paddlefish, which have developed a straining apparatus which enables even adult specimens to continue feeding on these tiny crustacea. The application of this knowledge has led to the growing of *Entomostraca* in culture to be used as food for fish in breeding ponds. Most commercial and game fish, however, are caught from lakes and/or rivers where they feed on the bounty provided by nature. A study of the *Entomostraca* in these bodies of water will provide us with some means of estimating the possibilities of stocking such lakes and/or rivers with commercial or game fish with some likelihood of their survival. Simply dumping fry or fingerlings into lakes which have not been thus examined may be wasteful indeed. A survey of the *Entomostraca* of Manitoba waters may therefore, be considered as basic to a knowledge of the fish populations these waters may be expected to support. It is the "watery equivalent" to a study of pasturage for grazing land animals.

The commercial fishing industry of Manitoba plays a very important part in the economy of this province. The average total productions for the twelve year period 1938-1950 was over 31,000,000 pounds of fish, and during the last three years the average annual value of fisheries production was over $5,000,000. It is interesting to note that in fiscal year 1938-1939 the total value of fisheries production was $1,769,000. while over

34,000,000 pounds of fish were produced in that year. In other words the annual value of fisheries production has multiplied about three times in the twelve year interval.

The number of fishermen employed in the winter fishery alone was nearly 7,000 in the fiscal year 1948-1949, and the value of boats, skiffs and other equipment used was nearly $2,500,000. About from one-third to one-half as many men were employed in the summer fishery.

So large is the province that the problem of supervision of commercial fishing is a difficult one and during the summer, on Lake Winnipeg, Lake Winnipegosis and Lake Manitoba, constant operation of patrol boats is required. These are diesel-powered and equipped with two-way radio. During the winter, Bombardier snowmobiles and a snowplane patrol the larger lakes of southern Manitoba. Difficulties of supervision are multiplied during the winter especially in the northern part of the province, where last year 62 lakes were involved in an area covering some 80,000 square miles. Bombardier patrols from The Pas covered many of the lakes in that immediate vicinity, and in addition a Bombardier was located at Gods Lake to patrol lakes of that area. It may be of interest to note that fish produced at South Indian Lake (No. 62, Fig. 24) during the winter was flown out in the fresh state.

Enough has been said to indicate the great importance of Manitoba's fishing industry. It is an industry whose continued expansion is assured as hundreds of smaller lakes are brought into production. This gigantic fisheries industry is entirely dependent upon *Entomostraca*. These tiny crustacea form the basis of the food supply of all fish, since all species feed upon *Entomostraca* in their infancy, and upon reaching maturity they either continue to feed upon *Entomostraca*, or they feed upon insects, fish, or other organisms which in turn feed upon *Entomostraca*. Thus, it will be seen how important the present study is to the welfare of this province.

ENTOMOSTRACA AS INTERMEDIATE HOSTS OF PARASITIC ORGANISMS

Various investigators have determined the life histories of tapeworms and of other parasites that infest fish, birds, and mammals. While it is true that complete life histories of many of these parasites are still to be determined by future investigation, yet partial or complete life histories of certain parasitic forms have been ascertained.

It is at first surprising to note how often *Entomostraca* are the first intermediate hosts for such parasites. Yet, on contemplation, how could it be otherwise! These parasites are absolutely dependent on reaching their second intermediate and final hosts via the alimentary canal, and to do so must be enclosed within the living food of the latter forms. Hence, *Entomostraca*, which form the food of almost all fish in their earliest stages and of many fish throughout life, provide the ideal means of accomplishing the desired result.

I am indebted to R. A. Wardle (1932, 1932a, 1933, 1933a, 1935), to R. A. Wardle and J. A. McLeod (1951), and to R. B. Miller (1944, 1945, 1946) for the following list compiled from their publications:

ORGANISM	FIRST Inter. Host	SECOND Inter. Hose	FINAL Host
1. *Hymenolepis brachycephala*	Cyclops sp.		Charadriiform Birds (Lapwings, plovers, turnstones)
2. *Hymenolepis collaris*	Diaptomus Cyclops Cypris		Anseriform Birds (Ducks, Geese, etc.)
3. *Hymenolepis coronula*	Cypridae		Anseriform Birds
4. *Hymenolepis gracilis*	Copepoda Ostracoda		Anseriform and Gruiform Birda (Cranes, etc.)
5. *Drepaindotaenia lanceolata*	Cyclops Diaptomus		Anseriform Birds
6. *Fimbriaria fasciolaris*	Cyclops Diaptomus		Anseriform Birds
7. *Cyathocephalus truncatus*	*Pontoporeia affinis*		*Coregonus clupeaformis* and *Salvelinus alpinus*
8. *Bothridium pithonis*	*Cyclops viridis*		
9. *Spirometra mausonoides*	Procercoid in Cyclops		
10. *Dibothriocephalus laruli*	Procercoid in *Diaptomus oregonensis*		
11. *Schistocephalus solidus*	Procercoid in Cyclops		
12. *Bothriocephalus rarus*	Procercoid in Cyclops		
13. *Triaenophorus crassus*	Procercoid in *Cyclops bicuspidatus thomasi*	Cisco and Whitefish	Pike (*Esox lucius*)

ORGANISM	FIRST Inter.Hose	SECOND Inter.Host	FINAL Host
14. *Triaenophorus nodulosus* (Pallas)	Procercoid in *Cyclops b. thomasi*	Ling or Burbot (*Lota maculosa*)	Pike (*Esox lucius*)
15. *Triaenophorus stizostedionis*	Procercoid in *Cyclops b. thomasi*	Trout Perch (*Percopsis omiscomaycus*	Pike-perch (*Stizostedion vitreum* Mitchill)
16. *Proteocephalus pinguis*	*Cyclops bicuspidatus*		Pike (*Esox lucius*)
17. *Diphyllobothrium latum*	Procercoid in *Diaptomus oregonsis*	Pickerel (*Luciopera vitreum*) Pike-perch (*Stizostedion vitreum*) Yellow Perch (Perca flavescens) Pike (*Esox lucius*) and (Esox estor)	Mammal

With constantly expanding knowledge due to the research of many workers in the field of helminthology, there are constantly being added new revelations of the importance of *Entomostraca* as intermediate hosts for parasitic worms. The need for teamwork between helminthologists and specialists working with microcrustacea is underlined, since it is obvious that such teamwork will be exceedingly fruitful.

In Manitoba the most immediate practical problem facing the fisheries industry is that of the infestation of ciscoes *Leucichthys* and whitefish, *Coregonus clupeaformis* with the second intermediate stage of the tapeworm, *Triaenophorus crassus*. The work of Miller (1944, 1945, 1946) has been outstanding both in tracing the life history of this parasite and in outlining various methods of attacking the problem presented by it. The author's studies of the percentage infestation of the crustacean host with procercoids of *Triaenophorus* are briefly summarized in the section dealing with *Cyclops bicuspidatus thomasi* in Part I of this thesis. Studies made by the author of the feeding of Lake Winnipeg ciscoes, which form Parts IV, V, and VI of this thesis are an additional contribution towards this phase of fisheries research.

THE VALUE OF A SURVEY OF THE ENTOMOSTRACA OF MANITOBA AS A CONTRIBUTION TO GENERAL KNOWLEDGE

One of the most stimulating features of this research has been the interest and encouragement offered by other workers in the field. Many of the *Entomostraca*, which the author found in Manitoba, are quite far out of their previously known range of distribution. Since unusual distribution records are open to some justifiable suspicion, the author has taken the precaution of having his identifications verified by outstanding authorities, for whose services fitting acknowledgment is made later in the text. These authorities have been kind enough to urge immediate publication of these new distribution records, and steps have been taken by the author to that end. The occurrence of *Senecella calanoides* in Manitoba was surprising indeed, as was the occurrence of *Diaptomus arcticus* and *Epischura nevadensis*. The author's publication of a description of a new species of *Diaptomus* (*Diaptomus manitobensis* Arnason, 1950) was of considerable interest to Mrs. M. S. Wilson to whom the author sent mounts of