1975

Parasitic Copepods of Chinook, Oncorhynchus tshawytscha (Walbaum), and Coho, Oncorhynchus kisutch (Walbaum), Salmon of Lake Michigan

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PARASITIC COPEPODS OF CHINOOK, Oncorhynchus tshawytscha (Walbaum), AND COHO, Oncorhynchus kisutch (Walbaum), SALMON OF LAKE MICHIGAN

by

Joseph K. Buttner

A Thesis Submitted to the Faculty of the Graduate School of Loyola University of Chicago in Partial Fulfillment of the Requirements for the Degree of Master of Science

February 1975
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INTRODUCTION

Few studies have been conducted on the parasitic copepods of the Great Lakes region, and no recent studies have been made on those of Lake Michigan. The flora and fauna of the Great Lakes region, in particular Lake Michigan, has been significantly altered during the last few decades. Most recent of these alterations is the addition of coho Oncorhynchus kisutch (Walbaum) and chinook Oncorhynchus tshawytscha (Walbaum) salmon to the Great Lakes region in the late 1960's. Subsequently, salmon have become not only ecologically important as a secondary carnivore, but also economically important as a game fish.

It is therefore necessary to determine the exact relationship of these introduced fish to other biota of the region. Parasitism of fish by copepods is hazardous and occasionally fatal to the host as found by Tidd (1934), Savage (1935), Uzman and Rayner (1958), and Gall, McClendon, and Schafer (1972); yet studies of parasitic copepods on salmon or any fish of the Great Lakes region are scanty. It is essential that this ecological and economical relationship between host and parasite be established and studied. The principle goal of this investigation is to determine the species, frequency, and preferences of copepods collected from captured salmon. A second objective is to maintain and observe the parasites under laboratory
conditions to determine mode of locomotion, frequency of detachment from host, egg hatch, and resulting larvae information. A final objective is to record the observed frequency, size, and egg capacity of copepods parasitizing salmon with the same copepod species observed on the original or primary Lake Michigan host.
LITERATURE REVIEW

Publications pertinent to the relationship of parasitic copepods to salmon of Lake Michigan are of five types; studies of copepods found within the Great Lakes region, studies of nearctic parasitic copepods, studies of parasitic copepods parasitizing salmon, studies pertaining to salmon of Lake Michigan, and other investigations and taxonomic works.

Works on copepods in the Great Lakes region are of two categories, those pertaining to parasitic forms and those to free-living forms. Identifications of fish parasites were conducted in Lake Erie by Bangham and Hunter (1939) and Lake Huron by Bangham (1955), but neither dealt specifically with parasitic copepods. Other investigations by Tidd (1929, 1931) in which parasitic copepods of Lake Erie were specifically inspected resulted in several new host-parasite relationships being recorded and a list of parasitic copepods indigenous to Lake Erie. Studies of Lake Michigan parasitic copepods are limited to work by Kellicott (1879) on a new species. Recent examinations of free-living Lake Michigan copepods by Wells (1960, 1970) and Gannon (1972) describe changes in zooplankton populations, to which all immature parasitic copepods belong.

Publications by Kellicott (1880, 1881, 1882) initiated increased interest in nearctic parasitic copepods. C.B.
Wilson (1903, 1904, 1905, 1911, 1915, 1925, 1944) added to existing information and provided not only the first comprehensive analysis and description of all North American parasitic copepod families, but also the first key using structural difference as a basis for species determination. Subsequent studies have been narrower, usually dealing with single or closely related species.

During the twentieth century several informative investigations have been conducted. Fasten (1914, 1921) examined *Salmincola* sp. and was the first to locate and describe a male of that genus. Henderson (1926) investigated *Ergasilus* sp. found on pike-perches in Canada and Bere (1931) conducted a similar study of parasitic copepods of northern Wisconsin. Meehean (1940) extensively analyzed existing material and revised the taxonomy of *Argulus* sp., which was challenged by Wilson (1944) resulting in much confusion which was cleared by Cressey (1972) with a revised key. Other studies include Smith (1949) on *Ergasilus* sp. east of the Mississippi River, Causey (1957, 1959, 1960) on a variety of parasitic copepods, Haley and Winn (1959) on the biology of *Lernaea* sp., Roberts (1965, 1969, 1969a) with descriptions of new species and redescriptions of known species *Ergasilus*, and Rogers (1969) with a description of a new species of *Ergasilus* and an attempted life study.

More recently detailed revisions of earlier descriptions and keys of North American parasitic copepod genera have been produced. The most comprehensive of these works is Yamaguti
(1963) describing and keying all known orders, families, and genera of parasitic copepods. Other works on individual genera have recently been published. Kabata (1969) revised and added several species to the genus Salmincola. Roberts (1970) published a similar revision of the species within the genus Ergasilus stressing structures not used in earlier keys.

Numerous studies on parasitic copepods of the Pacific Northwest have been conducted, many dealt with chinook and coho salmon. Among the earlier investigations were those of Fraser (1920) which included salmon and other fishes captured off Vancouver Island. Fasten (1921) studied the biology of Salmincola sp. parasitizing chinook salmon. Later investigations included the works of Uzman and Rayner (1958) on copepods parasitizing salmon and other fish of Oregon and Washington, and Cope (1959) who inspected fish from Alaskan streams. More recently Roberts (1963) investigated closely related ergasiloid species found parasitizing salmon of British Columbia. One of the few known life cycles of parasitic copepods was determined by Kabata and Cousens (1973) on a species parasitizing Pacific coast salmon.

Publications pertinent to salmon of Lake Michigan are of two types; those dealing specifically with salmon in the Lake and others investigating salmon in the laboratory or holding ponds. MacLean and Yodes (1970) investigated kidney disease among salmon of Lake Michigan, while Lister and
Genoe (1970) examined relations between cohabiting under-yearling chinook and coho salmon. Harney and Norden (1972) and Peck (1974) studied food habits of coho salmon in Lake Michigan. Analysis of the stocking procedures and commercial and economic effects of salmon in Lake Michigan was conducted by Scott (1973). Optimal environmental conditions for salmon in holding ponds and in laboratory facilities were determined by Burrows and Combs (1968) and Burrows (1970). Techniques for accurately aging salmon were established and discussed by Godfrey, Worlund, and Bilton (1968).

Several recent investigations not specifically related to parasitic copepods or salmon have proved invaluable. Muench (1958) studied the effects of quinaldine as a fish anesthetic. Contemporary scientific speciation for fish was listed by Bailey (1960), Eddy and Hodson (1970), and McPhail and Linsey (1970). Feeding habits of free-living cyclopoid copepods and nauplius larvae were investigated by Fryer (1957, 1957a) and Gaulig (1959). Pennak (1963) published a key to species of nearctic free-living cyclopoid copepods. This work included an excellent method of preserving and mounting cyclopoid specimens, much of which is applicable to arguloid and ergasiloid species. Hoffman (1967) examined parasites of freshwater fish, although parasitism by copepods was covered only briefly. Finally, unpublished information supplied through a personal communication with Hnath (Michigan Department of Natural Resources Fish
Pathologist) in 1973 indicates that data relative to parasitism by copepods upon Great Lakes region fish are incomplete.
METHODS AND MATERIALS

The parasite-host relationship of copepod to salmon found in Lake Michigan was approached by two methods. First, salmon from Lake Michigan were captured and examined for parasitic copepods. Second, specimens of both host and parasite were maintained and observed under laboratory conditions.

To facilitate this investigation, permission was obtained from Mr. Cochrane of Biotest Industrial Laboratories, Mr. Lupinot of the Illinois Department of Conservation, and Mr. MacGregor of the Michigan Department of Natural Resources to observe salmon captured during fish samplings of Lake Michigan. Sample sites were located on Lake Michigan at Toben Road, Wisconsin; Zion, Illinois; Waukegan, Illinois; Winnetka, Illinois; Montrose Harbor, Chicago, Illinois; Belmont Harbor, Chicago, Illinois; Diversey Harbor, Chicago, Illinois; Jackson Park Harbor, Chicago, Illinois; and Little Manistee River, Michigan (Figure 1). In addition, both the Illinois Department of Conservation and the Michigan Department of Natural Resources gave permission to observe salmon in rearing ponds prior to their introduction into Lake Michigan. During the fall of 1973 one hundred and two salmon were captured by the above three agencies and another one hundred and one were captured in the spring of 1974. All salmon captured were available for observation.
and collection of data.

Biotest Industrial Laboratories sampled Lake Michigan six days per month at three sites in Illinois and Wisconsin: off Waukegan, Illinois (Figure 2); Zion, Illinois (Figure 3); and Toben Road, Wisconsin. Biotest's sixty-three foot trawler, the Chamber Brothers (Figure 4), powered by a 320 Hp diesel engine and equipped with trawling and gill net apparatus, was docked at Kenosha, Wisconsin. Trawling was conducted four days per month at each sample site at depths of 12 ft., 18 ft., 30 ft., and 40 ft. using a Strohshaul 70 Hp wrench equipped with 1,200 ft. of 5/8 in. cable attached to a 51 ft. sample net. Gill nets were set for eighteen hours, two at the Waukegan site (24 ft. and 60 ft. water depth) and three at the Zion and Toben Road Sites (12 ft., 24 ft., and 60 ft. water depth). Trawling operations and gill net sets off Waukegan, Illinois ceased as of May, 1974. Each gill net consisted of four sections of 100 yd. 5-1/2 in. mesh, 100 yd. 3-1/2 in. mesh, 100 yd. 2-1/2 in. mesh, and 90 ft. 1-1/2 in. mesh. Trawling was conducted throughout the year and obtained few salmon. Gill nets were set as permitted by weather and proved to be the most effective method of capturing salmon.

The Illinois Department of Conservation used a 16 ft. jonboat powered by a 25 Hp Johnson outboard to set gill nets overnight at Montrose Harbor, Belmont Harbor (Figure 5), Diversey Harbor (Figure 6), and Jackson Park Harbor (Figure 7). In addition, electrofishing was conducted off
the Commonwealth Edison Winnetka plant (Figure 8), Diversey Harbor, and Jackson Park Harbor with a Homelite two cycle generator producing 230 volts A.C. at 7.5 amps. Sampling was conducted only during the fall when mature salmon enter harbors to spawn. Both techniques were effective in capturing salmon, over thirty fish were captured through both methods during the fall of 1974.

The Michigan Department of Natural Resources has spawning stations situated on the Platte River, Manistique River, and Little Manistee River. Operations on the Little Manistee River (Figure 9) harvested 15-20% of all harvested coho salmon and 100% of all harvested chinook salmon during 1972. Salmon were captured and retained in weirs until harvesting procedures were initiated. Fish to be harvested were removed with nets, stunned in Ms-22 (Tricaine methanesulfonate), and spawned. Both spawned and nonspawned salmon were observed. During the two week period in which the salmon were harvested an average of two hundred fish per day were handled. Three thousand coho salmon and twelve hundred and fifty chinook salmon returned to the weir during the fall of 1972.

Sampling procedures of each agency were recorded using a 35mm single lens reflex Alpa camera with a macro-switar lens and Agfachrome Ct-18 film. At the sample site, fish were measured and weighed using metric sticks and spring scales. Sex of fish, capture site, and condition of fish (alive or dead) were recorded and scale samples for age
determination (Figure 10) were taken at this time. Salmon were also observed grossly for parasitic copepods. Copepods found were isolated and carefully removed from the host and initially preserved in 70% ethanol. Gills and nostrils were dissected out with an Alpa fillet knife and preserved in 70% ethanol until transported to the laboratory where any parasites present were isolated.

In the laboratory, parasitic copepods were isolated and preserved in 70% ethanol or permanently mounted in Turtox mounting media (CMC-9AF). Preserved and/or mounted specimens were classified using the key of Roberts (1970) for *Ergasilus*. Classifications were verified by consultation with a specialist.

Observations and dissections were conducted with the aid of a Leitz binocular microscope with magnification to 250x. Greater magnification when needed was obtained from a standard compound scope with magnification to 1,000x. Copepod parasites and taxonomically important anatomical features were illustrated with the aid of an ocular reticule. A polaroid camera mounted on a cycloptic dissection microscope was also used where pictures could be effectively taken. Dissecting equipment included Irwin loops, minuten pin probes, watchmaker forceps, razor blade scalpels, and fine pointed scissors. Dissecting equipment was used to facilitate identification and illustration of copepod specimens. Techniques used in dissection were those developed by Pennak (1963).
Living parasitic copepods were captured and maintained in the laboratory. Parasitic copepods were obtained from yellow perch *Perca flavescens* (Mitchell) taken by hook and line from Montrose Harbor, Chicago, Illinois. Copepods were transported to the laboratory while attached to living yellow perch. In the laboratory several copepods, including all egg sac bearing specimens, were carefully dissected from the host. Other copepods were not removed, and the host was sacrificed. In both cases the living parasites were supplied with adequate oxygen, maintained in a varied photoperiod simulating actual conditions (initially 8 hrs. light and 16 hrs. dark, ultimately 12 hrs. light and 12 hrs. dark), and kept at 10°C.

Copepods bearing egg sacs were dissected free from their host and were maintained in 350 ml fingerbowls filled with lake water and observed for egg hatchability and examination of hatched larvae. Attempts to artificially attach copepods lacking egg sacs on salmon fingerlings were unsuccessful. Salmon fingerlings obtained from the Illinois Department of Conservation and the Michigan Department of Natural Resources for this purpose were released to Lake Michigan. Frequency and type of parasite locomotion was observed for both gravid and nongravid copepods.

Copepods remaining on sacrificed *P. flavescens* were maintained in liter beakers and observed after 18 hrs. The frequency of copepod detachments was determined. Gill nets set by Biotest Industrial Laboratories for 18 hrs. usually
produced many dead salmon making it necessary to determine whether parasite emigration occurred following the host's death. Observations of copepods of yellow perch during the 18 hr. test period determined the type of parasite locomotion while attached to gill filaments.
RESULTS AND DISCUSSION

Coho salmon *O. kisutch* (Figure 11) were initially introduced in 1966 to Lake Michigan by the Michigan Department of Natural Resources. Chinook salmon *O. tshawytscha* (Figure 12) were first stocked during 1967 in Lake Michigan also by the Michigan Department of Natural Resources. Both fish are quite similar in appearance; distinguishing features being a darkly pigmented mouth in *O. tshawytscha* (Figure 13) which is absent in *O. kisutch* (Figure 14), dark pigmented spots on the entire caudal fin of *O. tshawytscha* which appear only dorsally on *O. kisutch* (Figure 15), and nearly twice the number of intestinal caeca in *O. tshawytscha* than *O. kisutch*.

Both species of salmon, being relatively new arrivals to Lake Michigan, have had only a short time to establish parasite-host relationships. The present study examines these relationships between parasite and salmon. Further, one of the parasitic copepods observed from salmon hosts was found to parasitize yellow perch *P. flavescens*; this parasite-host relationship was examined and compared with that found to exist between salmon and parasite. Finally, observation of parasite anatomy and mobility was also conducted.
Parasite-Fish Relationships

Data from Chinook and Coho Salmon

Parasitic copepods of the genus *Ergasilus* were found to parasitize both chinook *O. tshawytscha* and coho *O. kisutch* salmon. No specimens from the genera *Salmincola* or *Lernaea* were observed on either Lake Michigan salmon, although previous studies by Uzman and Rayner (1958) and Kabata (1969, 1973) have shown salmon to be parasitized by species of these genera. Additional ergasiloid specimens were obtained from rainbow trout *Salmo gairdneri* (Richardson), brown trout *Salmo trutta* Linn., and yellow perch *P. flavescens*. *Ergasilus lucioperca* Henderson were observed on *O. tshawytscha*, *S. trutta*, *S. gairdneri*, and *P. flavescens*, while *O. kisutch* was parasitized by *Ergasilus nerkae* Roberts. This is the first report of *E. lucioperca* from *O. tshawytscha*, *S. trutta*, and *S. gairdneri*. *E. nerkae* was never before recorded on *O. kisutch*, although Roberts (1969) reported observing specimens on other salmonids. All ergasiloid specimens located were females; males remain free-living throughout their life and do not parasitize fish.

Nine specimens of *E. lucioperca* were obtained from seven parasitized *O. tshawytscha*. Eighty *O. tshawytscha* were captured and observations indicated a parasitism frequency of 8.75%. Results of a statistical analysis of the
parasitism rate of *E. luciopercarum* on *O. tshawytscha* indicate the actual rate of parasitism in the Lake to be 2.6%-15% at the 95% confidence level. One hundred and twenty-three specimens of *O. kisutch* were captured. Only two specimens of *O. kisutch* were parasitized, each by a single *E. nerkae*. *O. kisutch* from Lake Michigan observed during this study were parasitized at a frequency of 1.67%.

Statistical analysis conducted on observed rates *E. nerkae* on *O. kisutch* indicated a 0%-3.9% incidence of parasitism in Lake Michigan at the 95% confidence level.

Literature supports this low rate of parasite incidence under natural conditions. Bere (1931) examined approximately 1,300 fish and determined a rate of 2-1/2% parasitism by *Ergasilus confusus* Bere [(synonymous with *E. luciopercarum* according to Roberts (1969)]. Smith (1948) however, reported *Ergasilus centrachidarum* Wright infested *Micropterus salmoides* (Lacepede) at rates of 30 per fish and *Ergasilus caerulus* Wilson infested *Lepomus macrochirus* Raf. and *Pomoxis nigromaculatus* LeSeur at rates of over 250 per fish. This particular situation produced several fatalities. Fish mortality through copepod parasitism was recorded by Tidd (1934), Savage (1935), and Uzman and Rayner (1958). Reduced reproductive capacity of parasitized fish was reported by Gall, McClendon, and Schaefer (1972). In all cases fish mortality was recorded in unnatural conditions (e.g., rearing ponds). It appears that under natural conditions, such as those found in Lake Michigan,
parasitism of fish by copepods is of low incidence and has no deleterious effects.

Age distribution of host, sex of host, condition of host at capture, and capture site are examined with the rate of parasitism for each parameter. *O. tshawytscha* results are recorded in Table 1 (p. 18), while *O. kisutch* results are presented in Table 2 (p. 19). *E. lucioperca rum* exhibited little preference for male or female fish or between fish captured alive or dead. Using a Chi-square test neither variances in parasitism incidence regarding sex or host condition were statistically significant at the 95% level. The results of sex preference exhibited by *E. lucioperca rum* were, however statistically significant at the 90% level. Preferences did exist regarding host, age, and capture site.

*E. lucioperca rum* exhibited a marked preference for younger fish. Chi-square analysis at the 95% confidence level indicates *E. lucioperca rum* prefer *O. tshawytscha 1 year* or younger in age. This preference is in contradiction with findings of Fasten (1921) and Savage (1935). Parasitized salmon were observed more frequently from harbor environments than open waters. Chi-square analysis at the 95% confidence level indicates *O. tshawytscha* from harbors were preferred as hosts for *E. lucioperca rum* over those captured in open waters. The harbor environment would be frequented by younger *O. tshawytscha* fingerlings more often than older and larger salmon. The harbor environment would
Table 1. Copepod Parasitism of Chinook Salmon

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<td><strong>AGE</strong></td>
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<td></td>
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<tr>
<td>0 year+</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>1 year+</td>
<td>5</td>
<td>27</td>
</tr>
<tr>
<td>2 year+</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>3 year+</td>
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<td>1</td>
</tr>
<tr>
<td><strong>SEX</strong></td>
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</tr>
<tr>
<td>Immature</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Male</td>
<td>5</td>
<td>37</td>
</tr>
<tr>
<td>Female</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td><strong>CONDITION AT CAPTURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alive</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Dead</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
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<td>0</td>
<td>14</td>
</tr>
<tr>
<td><strong>CAPTURE SITE</strong></td>
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<td></td>
</tr>
<tr>
<td>Zion, Illinois</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Diversey Harbor, Illinois</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Little Manistee River,</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Michigan</td>
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<td></td>
</tr>
<tr>
<td>Toben Road, Wisconsin</td>
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<td>10</td>
</tr>
<tr>
<td>Montrose Harbor, Illinois</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Jackson Park Harbor,</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waukegan, Illinois</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Belmont Harbor, Illinois</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>7</td>
<td>73</td>
</tr>
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</table>
Table 2. Copepod Parasitism of Coho Salmon

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parasitized</th>
<th>Non Parasitized</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AGE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 year⁺</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>1 year⁺</td>
<td>1</td>
<td>95</td>
</tr>
<tr>
<td>2 year⁺</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td><strong>SEX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immature</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Male</td>
<td>0</td>
<td>63</td>
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<td>Female</td>
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<td></td>
</tr>
<tr>
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<td>23</td>
</tr>
<tr>
<td>Dead</td>
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<td>92</td>
</tr>
<tr>
<td>No record</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td><strong>CAPTURE SITE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zion, Illinois</td>
<td>1</td>
<td>73</td>
</tr>
<tr>
<td>Little Manistee River, Michigan</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Toben Road, Wisconsin</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Waukegan, Illinois</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Montrose Harbor, Illinois</td>
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<td>1</td>
</tr>
<tr>
<td>Jackson Park Harbor, Illinois</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Belmont Harbor, Illinois</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Diversey Harbor, Illinois</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>2</td>
<td>121</td>
</tr>
</tbody>
</table>
also, have the greatest quantity of plankton and therefore, the greatest concentration of immature parasitic copepods. The only parasitized *O. tshawytscha* captured from open waters was taken near a thermal plume off Waukegan, Illinois. Plumes being warmer than surrounding water would have greater quantities of plankton than surrounding open waters.

*O. kisutch* was parasitized so lightly that it is difficult to determine any parasite preferences. It is interesting that *O. kisutch* was parasitized by *E. nerkae*, not *E. luciopercarum*. This preference of *E. nerkae* for *O. kisutch* and *E. luciopercarum* for *O. tshawytscha* was statistically significant at the 95% level using a Chi-square test. Also, both *E. nerkae* specimens were collected from salmon captured in open waters not harbors, on females rather than males or immature *O. kisutch*, and on dead rather than living hosts. However, too few specimens were collected to conduct a statistical analysis.

**Comparison of Chinook Salmon and Yellow Perch Parasitism Rates**

According to Dogiel (1962) when a parasite occurs on more than one host it is most frequent, grows to the largest size, and produces the greatest number of eggs in one of these. According to Bere (1931), Tedla and Fernando (1969), and Roberts (1969) *E. luciopercarum* is found most frequently upon *P. flavescens*. These investigations suggest
E. luciopercarum from Lake Michigan prefer P. flavescens to O. tshawytscha.

One hundred and one P. flavescens from Lake Michigan were captured and observed. Twenty-seven specimens of E. luciopercarum were collected from sixteen P. flavescens. P. flavescens were taken by hook and line during August from Montrose Harbor, Chicago, Illinois. Specimens of E. luciopercarum taken from P. flavescens were more abundant, larger, and bore egg sacs more frequently than those obtained from O. tshawytscha. Numerical values are recorded in Table 3 (p. 22).

P. flavescens were parasitized much more frequently than O. tshawytscha. Only 8.75% of all O. tshawytscha observed were parasitized, while 15.8% P. flavescens bore parasites. P. flavescens bore an average of 1.67 parasites per fish with six specimens being the maximum observed on any individual. O. tshawytscha had an average of 1.43 parasites per fish with three specimens being the maximum taken from any fish. The greater percentage of parasitism by E. luciopercarum on P. flavescens rather than O. tshawytscha was not statistically significant. However, the greater frequency of multiple parasites on P. flavescens was statistically significant at the 95% level.

E. luciopercarum obtained from P. flavescens averaged 1.08mm, while those obtained from O. tshawytscha measured an average of .92mm. Maximum size of E. luciopercarum from P. flavescens exceeded the maximum size of specimens off
O. tshawytscha, minimum sizes were identical. Finally, egg sacs were observed on 13 P. flavescens, only a single egg sac was observed on E. luciopercarum from O. tshawytscha. At the 95% level the greater quantity of egg sacs observed on E. luciopercarum from P. flavescens was statistically significant. The larger size of E. luciopercarum taken from P. flavescens was not statistically significant at the 95% level, however at the 90% level it proved significant.

Table 3. Comparison of Copepod Infection of Chinook Salmon and Yellow Perch

<table>
<thead>
<tr>
<th>Parasite Information</th>
<th>Chinook</th>
<th>Perch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fish observed</td>
<td>80</td>
<td>101</td>
</tr>
<tr>
<td>Number of fish parasitized</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Number of parasites located</td>
<td>9</td>
<td>27</td>
</tr>
<tr>
<td>Average number of parasites per fish</td>
<td>1.28</td>
<td>1.69</td>
</tr>
<tr>
<td>Number of parasites bearing egg sacs</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Average size of parasite</td>
<td>max. = .95, min. = .92</td>
<td>max. = 1.45, min. = .86</td>
</tr>
</tbody>
</table>

Discussion of Determined Rates

Differences between parasitism rates and preferences upon the hosts could be due to two factors. E. luciopercarum
could prefer _P. flavescens_ over _O. tshawytscha_ as a host, agreeing with the theory proposed by Dogiel (1962). However, the season and water temperature at capture could also explain the different results.

All _E. lucioperca rum_ observed on _P. flavescens_ were obtained from Lake Michigan during August. August temperatures of Lake Michigan waters are among the highest for the year. Surface temperatures of Lake Michigan waters recorded during fish samplings in August were found to be consistently 20°C or higher. According to Wilson (1911), Smith (1948), and Rogers (1969) warming of waters initiates egg sac production. This would explain why _P. flavescens_ bore egg sacs more frequently than _O. tshawytscha_. Also, _E. lucioperca rum_ parasitizing _O. tshawytscha_ in the fall and not in the spring is possibly explained. More _E. lucioperca rum_ would be present during the fall than the spring. Many eggs hatch during the summer and the resulting larvae would mature to attachment size by the fall.

Why _E. nerkae_ should only be found on _O. kisutch_ and _E. lucioperca rum_ only on _O. tshawytscha_ is difficult to explain. Both species of salmon occur in similar habitats. Further, _O. kisutch_ species were initially stocked in Lake Michigan during 1966, while _O. tshawytscha_ species were not introduced until 1967. With more time to establish host-parasite relationships _O. kisutch_ would be expected to exhibit a higher rate of infestation than _O. tshawytscha_. This is not the case as indicated by my results. Although
reasons for these apparent contradictions were not examined, the larger size and more gregarious feeding habits of *O. tshawytscha* may be partially responsible.

**Parasite Information**

**Morphology**

*E. luciopercarum* (Figure 16) and *E. nerkae* (Figure 17) are quite similar in appearance. Both species appear cyclo-poid in form with two apparent regions, a large bulbous cephalothorax and five free thoracic segments (fourth segment is often obscure) followed by three abdominal segments. Mouthparts and the first pair of legs are located on the ventral cephalothorax. Dorsally the cephalothorax bears a single eyespot and the first and second antennae (second antennae is not shown on *E. nerkae*, Figure 17). The second antennae are used for host attachment usually on gill arch filaments. Each of the four readily observable thoracic segments bears a pair of legs ventrally. With the exception of the fifth leg, all legs are biramous, consisting of an endopodite and exopodite (Figures 18 and 19). The fifth leg is reduced to a single segment or a small papilla bearing setae. Visible on both *E. luciopercarum* and *E. nerkae* (Figures 16 and 17) are dorsal lateral projections located on the first free thoracic segment. The opening of the oviducts is located on the final (fifth) thoracic segment, behind which lies the abdomen. Extending from the
third abdominal segment is the telson with several terminal setae.

Taxonomically important features which aid in distinguishing *E. nerkae* and *E. luciopercarum* from other *Ergasilus* sp. are: the first leg, general body form, second antennae. The first leg of both *E. nerkae* and *E. luciopercarum* have endopodites composed of three segments (Figures 18 and 19). This separates both species from other ergasiloids which bear only two segments on their first endopodites. It further shows how closely they are related. When viewed dorsally the general shape of the cephalothorax in *E. nerkae* is more rounded and less elongated than that of *E. luciopercarum*. The most important taxonomic feature of the genus *Ergasilus* is the second antennae.

The second antennae of *E. luciopercarum* (Figure 20) and *E. nerkae* (Figure 21) are the most important taxonomic features distinguishing the two species. Close examination of the two antennae reveals a distal medial knob present on the third segment of *E. luciopercarum* which is absent in *E. nerkae*. Also, the third segment of *E. luciopercarum* is parallel and straight, while *E. nerkae* has a curved parallel third segment. Both species bear teeth on their fourth antennal segment.

**Host Preferences**

As previously determined *E. luciopercarum* prefers *P. flavescens* as a host to any of the salmonids, although
it was found on several. *E. nerkae* also exhibited a marked preference for *O. kisutch*. *E. luciopercarum* was originally described by Henderson from specimens obtained from pike-perch *Stizostedion vitreum* Mitchell. Bere (1931) found *E. luciopercarum* parasitizing lake trout *Salvelinus namaycush* (Walbaum), whitefish *Coregonus clupeaformis* (Mitchell), cisco *Coregonus artedi* (LeSeur), smallmouth bass *Micropterus dolomieu* (Lacepede), and rock bass *Amphloplites rupestris* (Rafinesque). Additional hosts were defined by Smith (1949), but his taxonomy has been questioned and revised by Roberts (1969). Roberts (1969) believed *E. luciopercarum* parasitized only Percidae, stating previous authors had confused *E. luciopercarum* with other species. It is apparent from my results that *E. luciopercarum* parasitizes salmonids as well as Percidae. *E. nerkae*, according to Roberts (1963, 1969) exhibits little host specificity, being found on salmonids, cyprinids, and catostomids.

**Attachment Preferences**

Wilson (1911) found *Ergasilus* sp. preferred the second gill arch to other attachment sites. From the results in Table 4, attachment sites for *E. luciopercarum* on both *P. flavescens* and *O. tshawytscha* appears random. In most cases parasites were located toward the tips of individual gill filaments (Figures 22, 23, and 24). *E. nerkae* was observed so infrequently (only two specimens were collected) that attachment preferences were not determined. Attachment
sites for E. nerkae on O. kisutch are reported in Table 4.

Table 4. Copepod Attachment Preferences on Chinook Salmon, Coho Salmon, and Yellow Perch

<table>
<thead>
<tr>
<th>Fish</th>
<th>Attachment Site</th>
<th>Right Gill Side</th>
<th>Arch</th>
<th>Left Gill Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinook</td>
<td>0</td>
<td>1st</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2nd</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3rd</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>4th</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Yellow Perch</td>
<td>6</td>
<td>1st</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2nd</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3rd</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4th</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Coho</td>
<td>0</td>
<td>1st</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2nd</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>3rd</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>4th</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Detachment Frequency**

Whether or not parasites detach after the host expires had to be determined. The majority of salmon observed were captured in gill nets set for 18 hours. Most salmon were dead when the nets were picked up, making it imperative to examine detachment rates on dead hosts for a 18 hour period. Results from Table 1 show nearly equal quantities of parasites were obtained from both living and dead hosts. Further,
a statistical analysis of observed parasitism rates on living and dead hosts indicated the deviations to be insignificant at the 95% level. But laboratory analysis of the situation was desirable.

To determine parasite detachment rates parasitized fish were required. Parasitized living *O. kisutch* or *O. tshawytscha* were not readily available. Artificial parasitism of salmon through introduction of mature *E. luciopercarum* to fingerlings of both *O. kisutch* and *O. tshawytscha* was attempted. *E. luciopercarum* dissected off *P. flavescens* gill filaments were placed together with salmon fingerlings, but they failed to attach. Attempts to mechanically place specimens upon gill filaments also failed.

Ultimately data was collected from *P. flavescens* captured by hook and line. *P. flavescens* were sacrificed, maintained at 10°C, and observed after 18 hours. Of fifteen *E. luciopercarum* originally attached, fourteen remained attached after 18 hours. Twelve of the fourteen were alive and two were dead.

Over 93% *E. luciopercarum* remained attached even though the host was dead for 18 hours. The high percentage of *E. luciopercarum* remaining attached to *P. flavescens* under laboratory conditions indicates the majority of *E. luciopercarum* would remain attached to *O. tshawytscha* dead in gill nets. This assumption is further supported since the maximum time a salmon could have been dead before observation would be 18 hours, most would have been dead
for a shorter time. (The nets would be filled gradually with fish, not immediately after being set.) Low detachment rates and salmon being dead for less than 18 hours strengthens the validity of the observed 8.75% parasitism rate by *E. luciopercarum* on *O. tshawytscha* in Lake Michigan.

**Locomotion**

*E. luciopercarum* were observed to determine what type of locomotion occurs, if any. Wilson (1911) noted that adult female ergasiloids exhibit diminished swimming capabilities. According to his findings detached specimens lie on their backs, swimming only under much provocation. Observed movement of *E. luciopercarum* did not include swimming, although beating of swimming legs was noted. Setae on swimming legs were broken off near their bases where, according to Henderson (1926) abscission planes developed following copepod attachment. This results in inhibition of swimming.

Henderson (1926) found *E. luciopercarum* at 0.85mm to have swimming setae while those larger than 0.91mm had setae broken off. Results from Table 3 indicate 0.86mm to be the smallest specimen of *E. luciopercarum* observed. It is possible that *E. luciopercarum* attaches at approximately 0.85mm, then undergoes morphological change resulting in growth and loss of swimming setae.

Attached *E. luciopercarum* were observed to open and close their prehensile second antennae only once. Freshly
detached specimens would immediately start violent and rapid opening and closing movements of their second antennae. This would be accompanied by rapid beating of swimming legs and flexure of the body at the metasome-urosome junction.

On gill filaments copepods tend to gather at the distal end of the individual filament. The swimming legs act as "stilts" (Henderson, 1926) and permit movement in a sliding fashion along the gill filament.

Rearing

An attempt to rear larvae from eggs to adult was made. Wilson (1911) believed female erasilsoids to be fertilized while still in the free living state. He also believed there was no definite breeding season, but Smith (1949) stated the breeding season is over by November. Eggs from *E. lucioperca* were readily available only during the summer months, especially August.

It was found that eggs would not hatch unless the developing embryo's body exhibited pigmentation. According to Wilson (1911) pigmentation appears first 50-60 hours prior to hatching, while Rogers (1969) determined eggs hatch within 24 hours if pigmentation is present. Neither author was able to rear eggs from the nonpigmented stage. Wilson (1911) suggested the oxygen requirement was too great for eggs to survive in artificial habitats. Specimens of *E. lucioperca* with eggs were taken directly off *P. flavescens* and placed in an aerated aquaria maintained
at 10°C. Eggs still did not develop, suggesting factors other than oxygen could be responsible.

_E. centrachidarum_ larvae reared from pigmented eggs were obtained by Wilson (1911). Rogers (1969) hatched *Ergasilus cyprinaceaous* Rogers larvae from pigmented eggs. Wilson (1911) was able to attain growth to the first copepodid stage, while Rogers (1969) was able to maintain larvae for two moults. _E. luciopercarum_ was successfully reared to 24 hours in this study.

Complete life cycle studies are not in existence for any ergasiloid. However, Kabata (1973) recently determined the life cycle of a related parasitic copepod, *Salmincola californiensis* Dana. While this particular species attaches within 24 hours after hatching, ergasiloid species do not attach prior to their last moult, or not at all. (*Ergasilus chautauquanesis* Fellows, according to Wilson (1911) and Roberts (1969), has never been recorded from a fish host and only has been captured in tow.) Data from Kabata (1973) and Wilson (1911) indicate that maturity in different genera of parasitic copepods from egg to adult requires 4-9 weeks.
CONCLUSION

A number of statements can be made regarding the results of this study. Definite host-parasite relationships between copepods and Lake Michigan salmon have been established. *E. luciopercarum* and *E. nerkae* were found to parasitize *O. tshawytscha* and *O. kisutch* respectively. *E. luciopercarum* was also observed from several other salmonids and *P. flavescens*. Statistically significant preferences were exhibited by *E. nerkae* parasitizing *O. kisutch* and *E. luciopercarum* parasitizing *O. tshawytscha*. Further, statistically significant preferences were exhibited by *E. luciopercarum* relative to age and capture site of *O. tshawytscha*. At no time were rates of infection for any examined host excessive or harmful.

*E. luciopercarum* was found to prefer *P. flavescens*, although it was observed frequently on several salmonids. *E. luciopercarum* collected from *P. flavescens* were more numerous, grew to larger sizes, and bore egg sacs more frequently than specimens obtained from *O. tshawytscha*. These results, although not always statistically significant, indicate *E. luciopercarum* prefers *P. flavescens* over *O. tshawytscha* as a host.

Locomotion, detachment rates, egg hatch and early larval studies were conducted on *E. luciopercarum*. Locomotion is limited; swimming ability was not demonstrated, although
movement of both appendages and body does occur. Detachment of parasite from host is physically possible, although it occurred infrequently. Hatchability of eggs under laboratory conditions is reduced, but possible when eggs are obtained in the pigment stage. Maintenance and rearing of hatched larvae proved futile, with few specimens surviving for longer than 24 hours. Presently, no complete life cycle study of Ergasilus sp. exists.

Further investigations are necessary in a number of areas. Larger quantities of O. kisutch need to be sampled to obtain statistically sound results. Parasitism rates of other fish species in Lake Michigan must be investigated and compared with rates observed on O. kisutch and O. tshawytscha. Finally, physiological needs of Ergasilus sp. in the larval stage must be determined prior to any successful life cycle study.
LIST OF ABBREVIATIONS

The abbreviations were selected from Snodgrass (1965) were applicable. Others were devised for the purposes of this study.

abd .................................. Abdomen
1Ant .................................. First Antennae
2Ant .................................. Second Antennae
ant\textsubscript{1}sg .................. First Antennal Segment
ant\textsubscript{2}sg .................. Second Antennal Segment
ant\textsubscript{3}sg .................. Third Antennal Segment
ant\textsubscript{4}sg .................. Fourth Antennal Segment
cph .................................. Cephalothorax
dlp .................................. Dorsal Lateral Projection
dmk .................................. Distal Medial Knob
E .................................. Eyespot
endpd .................................. Endopodite
expd .................................. Exopodite
met .................................. Metasome
s_1 .................................. Toben Road sample site
s_2 .................................. Zion sample site
s_3 .................................. Waukegan sample site
s_4 .................................. Winnetka sample site
s_5 .................................. Chicago sample site
s_6 .................................. Jackson Park sample site
s7 ........................ Little Mainstee sample site
se ........................ Setae
swl ........................ Swimming Leg
uro ........................ Urosome
EXPLANATION OF FIGURE 1

1. Map of Lake Michigan sample sites. Belmont Harbor, Diversey Harbor, and Montrose Harbor sample sites are collectively shown as Chicago sample site. Abbreviations from map indicate sites:

$s_1$ . . . . . . . . . . . . . Toben Road sample site
$s_2$ . . . . . . . . . . . . . Zion sample site
$s_3$ . . . . . . . . . . . . . Waukegan sample site
$s_4$ . . . . . . . . . . . . . Winnetka sample site
$s_5$ . . . . . . . . . . . . . Chicago sample site
$s_6$ . . . . . . . . . . . . . Jackson Park sample site
$s_7$ . . . . . . . . . . . . . Little Manistee sample site
EXPLANATION OF FIGURES 2-6


4. Chamber Brothers, sampling vessel of Biotest Industrial Laboratories, docked at Kenosha, Wisconsin.

5. Belmont Harbor, Chicago, Illinois sample site. Note arrow pointing to pennant, indicating the location of gill net.

6. Diversey Harbor, Chicago, Illinois sample site. Note arrow pointing to pennant, indicating the location of gill net.
EXPLANATION OF FIGURES 7-9

   Note arrow pointing to pennant, indicating the location of gill net.

8. Electrofishing at Winnetka, Illinois sample site.
   Sampling is being conducted in the intake pool of the Commonwealth Edison Power Plant. Jon boat was also used for electrofishing.

9. Little Manistee River, Michigan, sample site. Holding weirs containing salmon to be spawned.
EXPLANATION OF FIGURES 10-15

10. Scale of chinook salmon, 100x. Note arrow indicating annulus formed at the conclusion of one year's growth.


13. Pigmented mouth of chinook salmon.


15. Pigmented spots of caudal fin of chinook salmon (lower fish), absent in coho salmon (upper fish).
EXPLANATION OF FIGURES 16-17

16. *Ergasilus luciopercarum*, dorsal view, 64x.
17. *Ergasilus nerkae*, dorsal view, 64x.
EXPLANATION OF FIGURES 18-19

18. First leg of *E. luciopercarum*, right leg, lateral view, 430x. Note both endopodite and exopodite are three segmented.

19. First leg of *E. nerkae*, right leg, lateral view, 430x. Note both endopodite and exopodite are three segmented.
EXPLANATION OF FIGURES 20-21

20. Second antennae of *E. luciopercarum*, left antennae, lateral view, 430x.

21. Second antennae of *E. nerkae*, left antennae, lateral view, 430x.
EXPLANATION OF FIGURES 22-24

22. Gills of chinook salmon. Note fungal growth on gill filaments indicated by arrow. Several chinook salmon bore this fungal infection.

23. *E. lucioperca*rum located on tips of gill filaments, 15x. Specimens are indicated by arrows.

24. Close-up of *E. lucioperca*rum on tips of gill filaments, 25x.
LITERATURE CITED


APPROVAL SHEET

The thesis submitted by Joseph K. Buttner has been read and approved by the following Committee:

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

1-11-75
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