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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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Few studies have been conducted on the parasitic cope-
pods 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 rela-
tionship 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, McClen-
don, 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 rela-
tionship between host and parasite be established and
studied. The principle goal of this investigation is to
determine the species, frequency, and preferences of cope-
pods collected from captured salmon. A second objective is
to maintain and observe the parasites under laboratory

1

conditions to determine mode of locomotion, frequency of
detachment from host, egg hatch, and resulting larvae in-
formation. 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 orig-
inal or primary Lake Michigan host.

LITERATURE REVIEW

Publications pertinent to the relationship of parasitic
copepods to salmon of Lake Michigan are of five types; stu-
dies of copepods found within the Great Lakes region, stu-
dies 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 speci-
fically inspected resulted in several new host-parasite re-
lationships 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 commer-
cial and economic effects of salmon in Lake Michigan was
conducted by Scott (1973). Optimal environmental condi-
tions for salmon in holding ponds and in laboratory facil-
ities were determined by Burrows and Combs (1968) and Bur-
rows (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) pub-
lished a key to species of nearctic free-living cyclopoid
copepods. This work included an excellent method of pre-
serving and mounting cyclopoid specimens, much of which is
applicable to arguloid and ergasiloid species. Hoffman
(1967) examined parasites of freshwater fish, although para-
sitism by copepods was covered only briefly. Finally, unpub-
lished 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 con-
ditions.

To facilitate this investigation, permission was ob-
tained from Mr. Cochrane of Biotest Industrial Laboratories,
Mr. Lupinot of the Illinois Department of Conservation, and
Mr. MacGregor of the Michigan Department of Natural Re-
sources to observe salmon captured during fish samplings of
Lake Michigan. Sample sites were located on Lake Michigan
at Toben Road, Wisconsin; Zion, Illinois; Waukegan, Illi-
nois; Winnetka, Illinois; Montrose Harbor, Chicago, Illi-
nois; Belmont Harbor, Chicago, Illinois; Diversey Harbor,
Chicago, Illinois; Jackson Park Harbor, Chicago, Illinois;
and Little Manistee River, Michigan (Figure 1). In addi-
tion, 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

8

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 opera-
tions 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 knive 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 in-
troduced 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 caecae 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 con-
ducted.

14

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, al-
though 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 (Richard-
son), brown trout Salmo trutta Linn., and yellow perch
P. flavescens. Ergasilus luciopercarum Henderson were ob-
served on O. tshawytscha, S. trutta, S. gairdneri, and
P. flavescens, while O. kisutch was parasitized by Ergas-
ilus nerkae Roberts. This is the first report of E. lucio-
percarum from O. tshawytscha, S. trutta, and S. gaidneri.
E. nerkae was never before recorded on O. kisutch, although
Roberts (1969) reported observing specimens on other sal-
monids. All ergasiloid specimens located were females;
males remain free-living throughout their life and do not
parasitize fish.

Nine specimens of E. luciopercarum were obtained from
seven parasitized O. tshawytscha. Eighty O. tshawytscha
were captured and observations indicated a parasitism fre-
quency 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. luciopercarum 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. luciopercarum were, however statistically significant at the 90% level. Preferences did exist regarding host, age, and capture site.

E. luciopercarum exhibited a marked preference for younger fish. Chi-square analysis at the 95% confidence level indicates E. luciopercarum 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. luciopercarum 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

Parameter	Parasitized	Non Parasitized
AGE		
0 year[+]	2	22
1 year[+]	5	27
2 year[+]	0	23
3 year[+]	0	1
SEX		
Immature	2	14
Male	5	37
Female	0	22
CONDITION AT CAPTURE		
Alive	3	23
Dead	4	36
No record	0	14
CAPTURE SITE		
Zion, Illinois	0	21
Diversey Harbor, Illinois	2	15
Little Manistee River, Michigan	0	11
Toben Road, Wisconsin	0	10
Montrose Harbor, Illinois	0	7
Jackson Park Harbor, Illinois	3	5
Waukegan, Illinois	1	4
Belmont Harbor, Illinois	1	0
TOTAL	7	73

Table 2. Copepod Parasitism of Coho Salmon

Parameter	Parasitized	Non Parasitized
AGE		
0 year[+]	1	15
1 year[+]	1	95
2 year[+]	0	11
SEX		
Immature	0	15
Male	0	63
Female	2	43
CONDITION		
Alive	0	23
Dead	2	92
No record	0	6
CAPTURE SITE		
Zion, Illinois	1	73
Little Manistee River, Michigan	0	16
Toben Road, Wisconsin	1	16
Waukegan, Illinois	0	13
Montrose Harbor, Illinois	0	1
Jackson Park Harbor, Illinois	0	1
Belmont Harbor, Illinois	0	1
Diversey Harbor, Illinois	0	0
TOTAL	2	121

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, Illi-
nois. 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 dif-
ficult to determine any parasite preferences. It is in-
teresting 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 statis-
tically 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 abund-
ant, 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. tshawyt-
scha 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

Parasite Information	Chinook	Perch
Number of fish observed	80	101
Number of fish parasitized	7	16
Number of parasites located	9	27
Average number of parasites per fish	1.28	1.69
Number of parasites bearing egg sacs	1	13
Average size of parasite	.92 max. = .95 min. = .86	1.08 max. = 1.45 min. = .86

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). How-
ever, the season and water temperature at capture could also
explain the different results.

All E. luciopercarum observed on P. flavescens were
obtained from Lake Michigan during August. August tempera-
tures 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 pro-
duction. This would explain why P. flavescens bore egg sacs
more frequently than O. tshawytscha. Also, E. lucioper-
carum parasitizing O. tshawytscha in the fall and not in
the spring is possibly explained. More E. luciopercarum
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. luciopercarum only on O. tshawytscha is difficult to ex-
plain. 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 seg-
ment 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 excep-
tion 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 seg-
ment, behind which lies the abdomen. Extending from the

third abdominal segment is the telson with several terminal
setae.

Taxonomically important features which aid in distin-
guishing 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 fur-
ther shows how closely they are related. When viewed dor-
sally the general shape of the cephalothorax in E. nerkae
is more rounded and less elongated than that of E. lucio-
percarum. 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 namaya-cush (Walbaum), whitefish Coregonus clupeaformis (Mitchell), cisco Coregonus artedi (LeSeur), smallmouth bass Micropterus dolomieui (Lacepede), and rock bass Amploplites 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 para-sitized only Percidae, stating previous authors had con-fushed 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 sal-monids, 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 <u>E</u>. <u>nerkae</u> on <u>O</u>. <u>kisutch</u> are reported in Table 4.

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

Fish	Attachment Site		
	Right Gill Side	Arch	Left Gill Side
Chinook	0	1st	3
	1	2nd	1
	2	3rd	0
	0	4th	0
Yellow Perch	6	1st	1
	5	2nd	2
	3	3rd	0
	5	4th	5
Coho	0	1st	0
	1	2nd	0
	0	3rd	1
	0	4th	0

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 para-
sites 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) abcission 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 ergasiloids 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. luciopercarum 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. luciopercarum 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 cope-
podid 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. (Ergasi-
lus 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 re-
sults of this study. Definite host-parasite relationships
between copepods and Lake Michigan salmon have been estab-
lished. E. luciopercarum and E. nerkae were found to para-
sitize 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, sta-
tistically 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 fre-
quently 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 lar-
val 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.
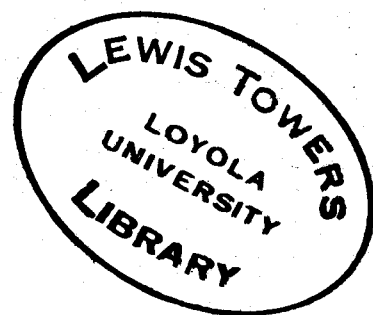
LIST OF ABBREVIATIONS

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_1sg . . . . First Antennal Segment

ant_2sg . . . . Second Antennal Segment

ant_3sg . . . . Third Antennal Segment

ant_4sg . . . . 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

34

s_7 . . . . 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. Abbrevia-
    tions 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
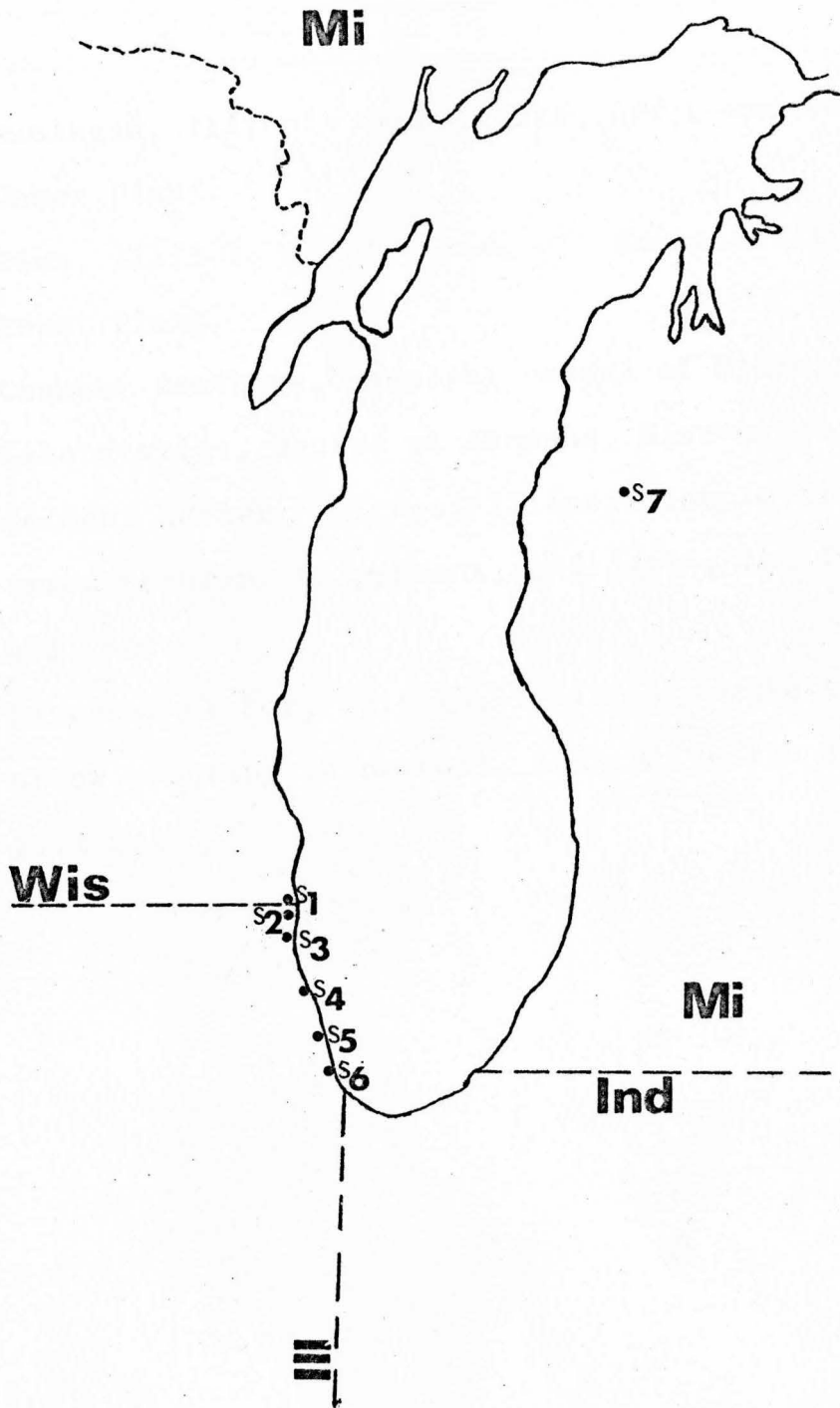
EXPLANATION OF FIGURES 2-6

2. Waukegan, Illinois sample site, off Commonwealth Edison
   Power Plant.

3. Zion, Illinois sample site, off Commonwealth Edison
   Power Plant.

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
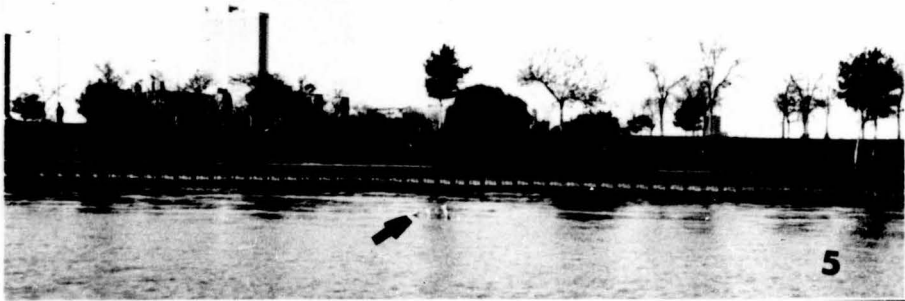   gill net.

EXPLANATION OF FIGURES 7-9

7. Jackson Park Harbor, Chicago, Illinois sample site.
    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
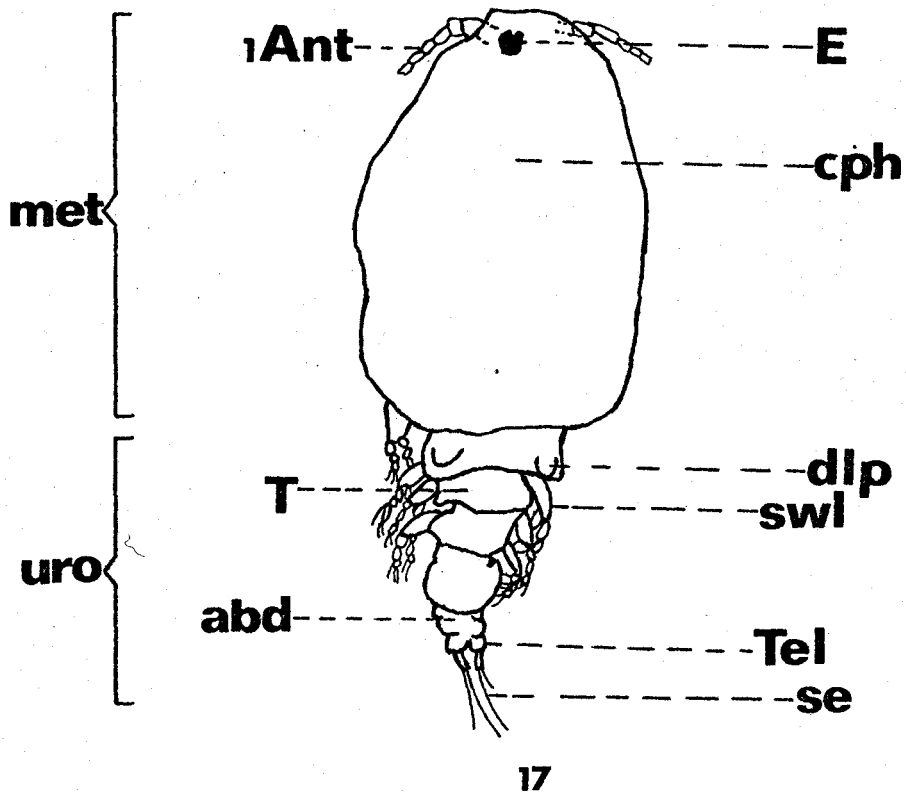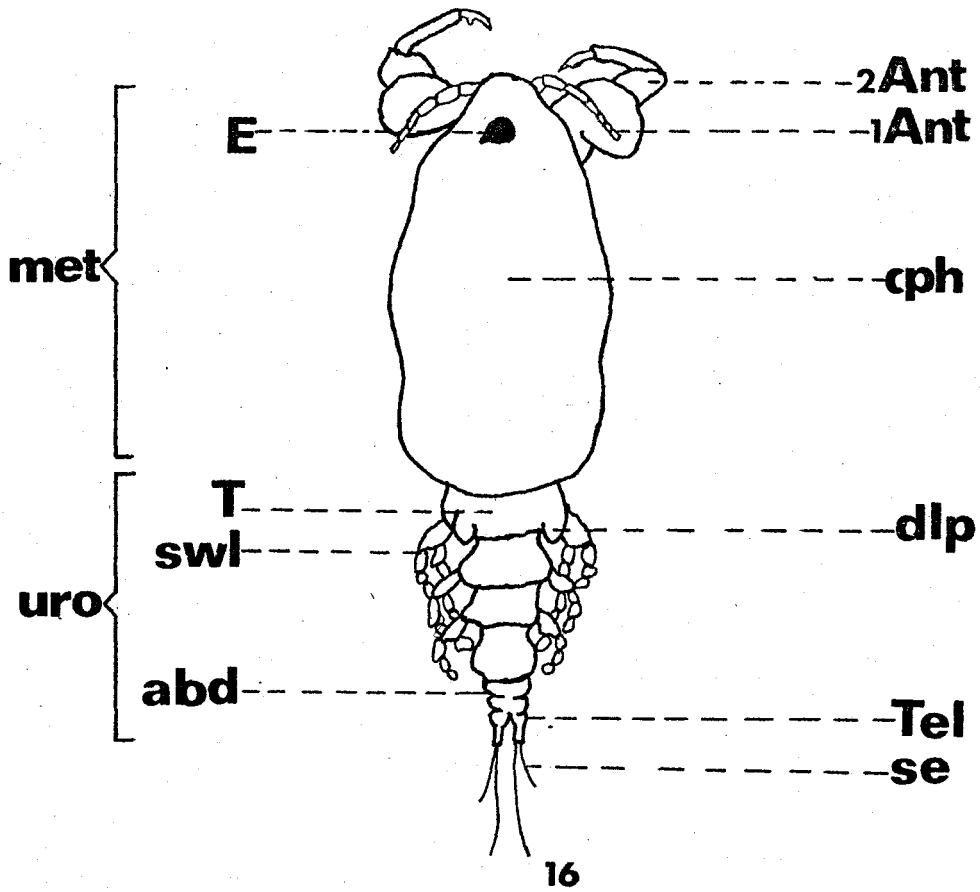   weirs containing salmon to be spawned.
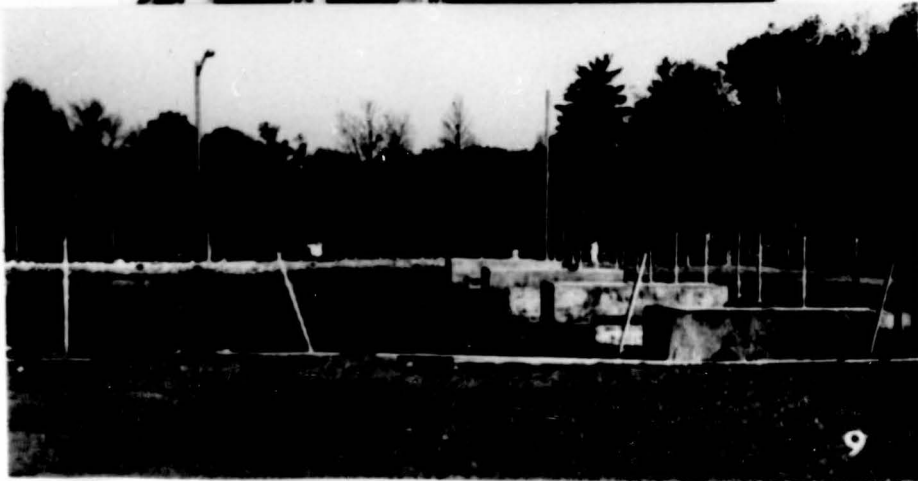
EXPLANATION OF FIGURES 10-15

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

11. Coho salmon <u>Oncorhynchus</u> <u>kisutch</u>, lateral view. Note light pigmented body.

12. Chinook salmon <u>Oncorhynchus</u> <u>tshawytscha</u>, lateral view. Note dark pigmented body.

13. Pigmented mouth of chinook salmon.

14. Nonpigmented mouth of coho salmon.

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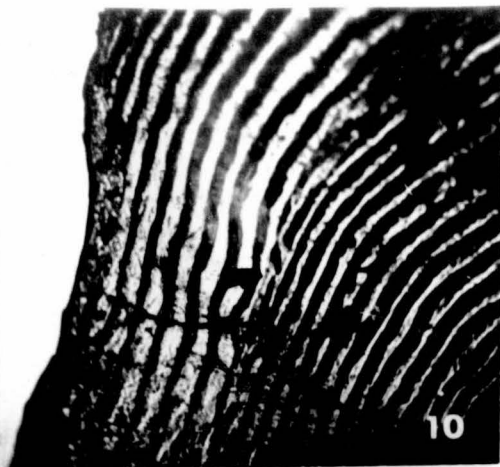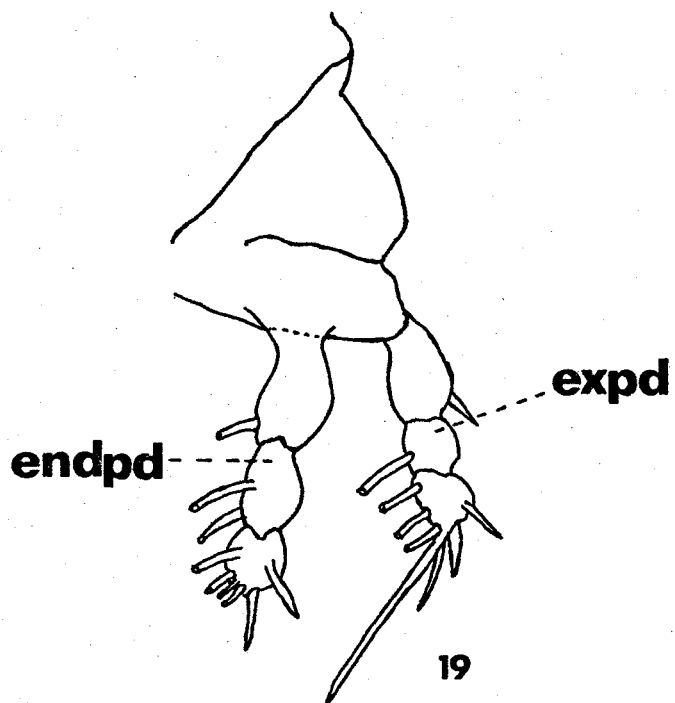
EXPLANATION OF FIGURES 16-17

16. <u>Ergasilus</u> <u>luciopercarum</u>, dorsal view, 64x.

17. <u>Ergasilus</u> <u>nerkae</u>, dorsal view, 64x.

2Ant
1Ant
E
met
cph
T
swl
uro
dlp
abd
Tel
se

16

1Ant
E
met
cph
T
dlp
swl
uro
abd
Tel
se

17

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.

expd

endpd

18

expd

endpd

19
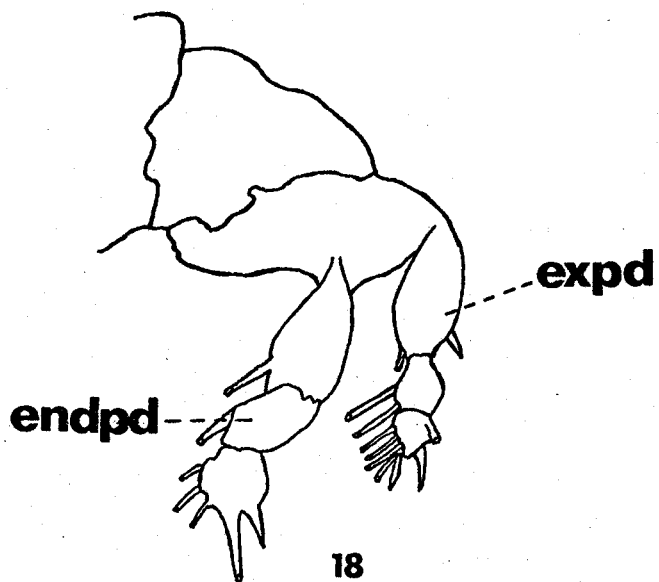
EXPLANATION OF FIGURES 20-21

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

21. Second antennae of E. nerkae, left antennae, lateral view, 430x.

ant₃ sg — $ant_3\ sg$

ant₄ sg — $ant_4\ sg$

dmk

ant₂ sg — $ant_2\ sg$

ant₁ sg — $ant_1\ sg$

20

ant₄ sg — $ant_4\ sg$

ant₃ sg — $ant_3\ sg$

ant₂ sg — $ant_2\ sg$

ant₁ sg — $ant_1\ sg$

21
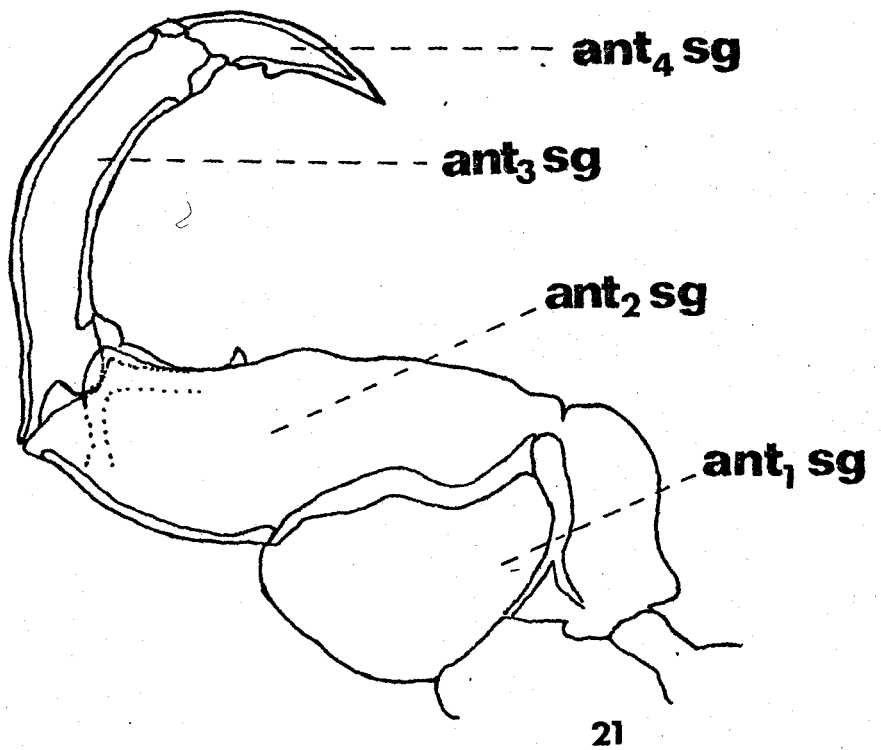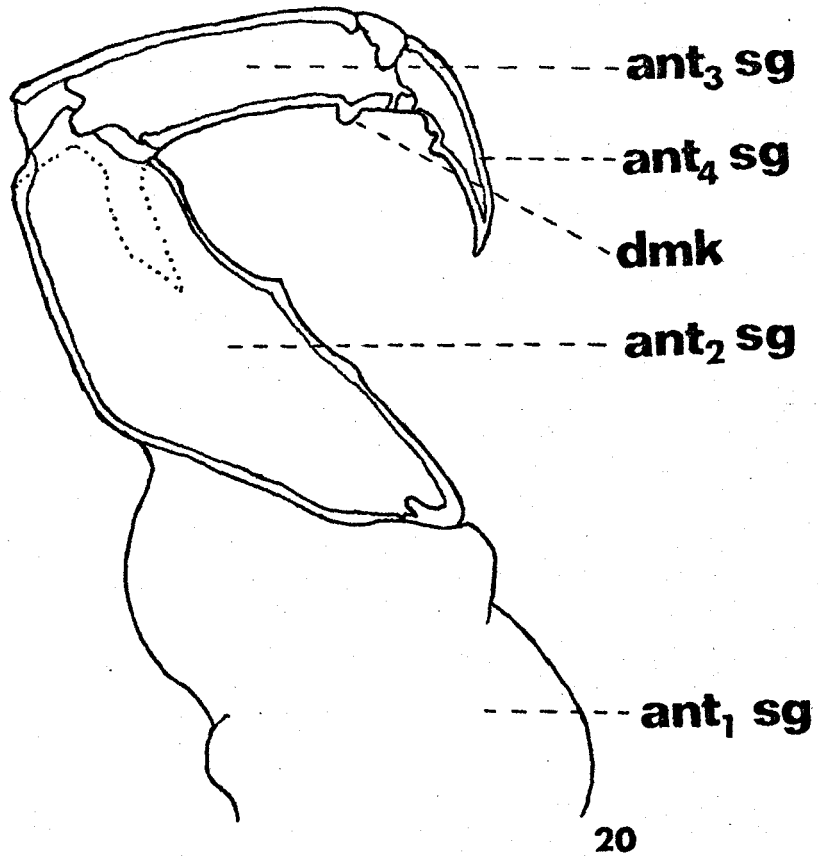
EXPLANATION OF FIGURES 22-24

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

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

24. Close-up of E. luciopercarum on tips of gill filaments,
    25x.

22

23

24

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The final copies have been examined by the director of the
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fact that any necessary changes have been incorporated and
that the thesis is now given final approval by the Committee
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The thesis is therefore accepted in partial fulfillment
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