# THE EFFECT OF *TRIAENOPHORUS CRASSUS* ON THE CONDITION OF *COREGONUS ARTEDI*

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***Abstract*—Cisco *Coregonus artedi* is, historically, the largest commercial fishery in the Great Lakes. The species is also important to commercial and recreational fisheries in inland lakes. Tapeworm *Triaenophorus crassus* larvae embed themselves into the flesh of Ciscoes, rendering the fish unmarketable to humans. *Triaenophorus crassus* is common in inland waters such as Leech Lake and Cass Lake, MN. One Canadian researcher has suggested that the parasite negatively affects the growth and weight of Ciscoes. Poor condition can reduce fecundity, leading to lower recruitment rates. This would mean a detrimental impact on not only individual fish, but the health of the entire population. The goal of this study was to determine whether a relationship exists between the severity of *T. crassus* infection and the condition of adult Ciscoes. Fish were sampled on Lake Bemidji, a medium sized mesotrophic lake, which represents inland Cisco habitat well. Both a standard weight equation and percent dry fillet weight were used to estimate fish condition. The severity of *T. crassus* infections were quantified by the number of cysts in relation to the wet weight (g) of muscular tissue on each specimen. Regression analyses suggested that both condition metrics were negatively correlated with the severity of *T. crassus* infection.**

## I. INTRODUCTION

Cisco *Coregonus artedi* is a species of high ecological and economical importance in Canada and the Northern United States. The species serves as forage for apex predatory fishes in lakes it inhabits. Studies suggest they increase the trophy potential for Walleye *Sander vitreus* when available (Kaufman et al. 2009). Ciscoes are also vital to commercial fisheries. For example, when harvest peaked in the late 19th century there was an annual Cisco harvest of 9 million kilograms on Lake Michigan alone (Claramunt et al. 2019).

An issue for inland Cisco fisheries is that many inland lakes hold populations of pikes *Esox* spp. Ciscoes in such systems are susceptible to infections of parasitic tapeworms *Triaenophorus crassus* (Appendix A). The life cycle of *T. crassus* uses several intermediate hosts before maturing in the definitive host, a pike. The tapeworms release their eggs into the water from a pike's intestine in the spring when the fish spawns. The eggs develop into coracidia, a free-swimming form that is then consumed by copepods. Inside the copepod, the coracidium develops into a procercoid. If the infected copepod is consumed by a suitable planktivorous fish, in this case a Cisco, the procercoid moves through the intestinal wall and into the muscular tissue of the fish. It then develops into a plerocercoid. The immune system of the Cisco then forms large cysts around the plerocercoid. In high concentrations, the cysts render the fish unmarketable to human consumers. If the Cisco is eaten by *Esox* spp., the plerocercoid will mature into an adult in the intestine of the predator, completing the life cycle of the tapeworm (Lahnsteiner et al. 2009).

Mesotrophic lakes in Northwestern Minnesota provide an abundance of each organism required to complete the life cycle of *T. crassus*. Variable and occasionally severe infestations of these parasites have been observed in adult Ciscoes in Lake Bemidji. The effect of *T. crassus* in Ciscoes has not been extensively documented. Canadian studies suggest that severe *T. crassus* infestations reduce growth rates and weight of the affected Ciscoes (Miller 1945, 1952). If this relationship exists, it could potentially reduce the forage value of the fish. The objective of this study was to quantify concentrations of *T. crassus* and the effect they have on the condition of adult Ciscoes on Lake Bemidji.

## II. METHODS

The Ciscoes used in this study were all captured from Lake Bemidji using standard angling equipment. Samples were collected from January 6th to February 9th, 2024. Upon capture, the fish were given an ID. Wet weight (g) and total length (mm) of the specimens were also recorded at this time. The specimens were then placed in bags labelled with the corresponding ID before being frozen for further analysis in the laboratory.

Fish were thawed for processing in the laboratory. Specimens were filleted and the total weight (g) of the fillets was recorded for each fish. Otoliths were also taken for aging at this time as well as the sex of each specimen. Fillets were then placed in aluminum pans for dissecting and drying. Cysts (Appendix A) were counted in each fillet and summed to obtain a total parasite count for each specimen. After counting, the fillets were retained in the drying pans which were then placed in an oven at 70° C. The fillets were left in the oven until their weight no longer decreased. At this point the dry weight (g) was recorded, and the specimens were discarded.

Two methods were used to compare the condition of specimens. The first was relative weight obtained by Equation 1, a standard weight equation developed for inland populations of Cisco (Fisher and Fielder 1998). The second method of condition estimation was a ratio between the wet and dry weights of the specimens' fillets. This allowed measurement of comparative lipid content between the specimens. Density of *T. crassus* was calculated as a ratio between total cysts and wet fillet weight. Regression analyses were performed for both condition estimates as well as for age in relation to density of *T. crassus* cysts. A regression was also used to assess the predictive capabilities of relative weight for percent dry fillet weight.

$$\log_{10}(W_w) = -5.716 + 3.289\log_{10}(L)$$

**Equation 1:** This equation was generated for inland populations of Cisco (Fisher and Fielder 1998). Wet weight (g) is represented by $W_w$ and total length (mm) by L.

## III. RESULTS

A total of 45 Cisco specimens were processed for this study, 9 males and 36 females. Ages ranged from 3 to 12 years, and every specimen was mature. Prevalence of *T. crassus* was 97.7%. Infection severity was highly variable, with abundances ranging from 0 to 28 cysts per fish ($\mu = 9$, $\sigma = 6.5$) and densities ranging from 0 to 178 cysts per kilogram (p/kg; $\mu = 38.9$, $\sigma = 32.0$). The highest mean abundance occurred in age 9 (12.7 cysts per fish) and the highest mean density in age 8 (54.3 p/kg). Condition estimates using standard weight ranged from 69 to 120 ($\mu = 90$, $\sigma = 9$). Dry weight retention ranged from 17.0% to 21.1% ($\mu = 18.9$, $\sigma = 1.1$).

When testing for relationships between parasite density and other metrics, a logarithm transformation was performed on the parasite density, which was positively skewed (Figure 5). This normalized the spread of parasite densities and yielded a more linear relationship between the variables (Figures 1, 2, 4 and 5).

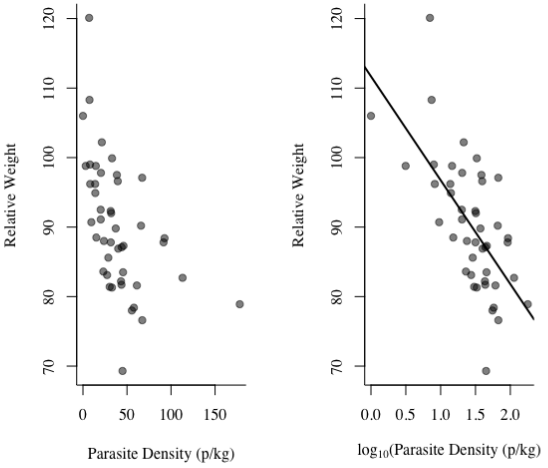

Fig. 1 (Left) The relationship between relative weight (*Wr*) and parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between relative weight (*Wr)* and the $\log_{10}$ transformation of parasite density (*D*) for *C. artedi.* A regression analysis yielded the model ($Wr = -14.94(\log_{10}(D)) + 111.68$, $R^2 = 0.43$, $P < 0.001$).

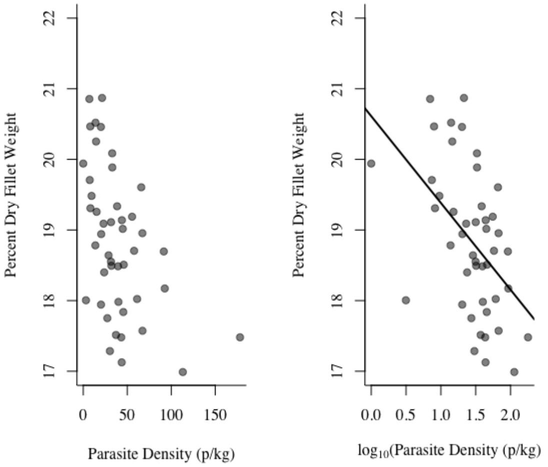

Fig. 2 (Left) The relationship between percent dry fillet weight and parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between percent dry fillet weight (*Wd*) and the $\log_{10}$ transformation of parasite density (*D*). A regression analysis yielded the model ($Wd = -1.22(\log_{10}(D)) + 20.61$, $R^2 = 0.24$, $P < 0.001$).

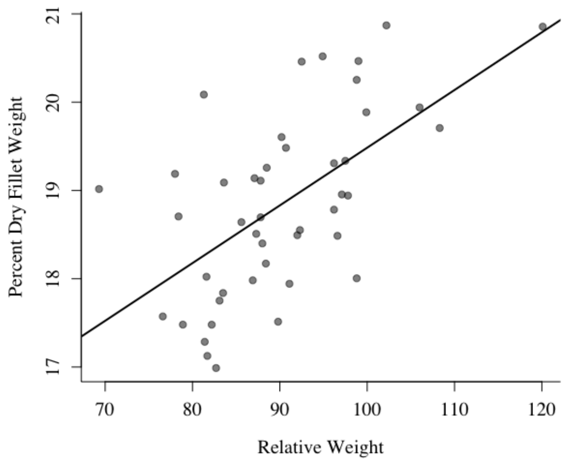

Fig. 3. The relationship between percent dry fillet weight (*Wd*) and relative weight (*Wr*) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. A regression analysis yielded the model ($Wd = 0.065Wr + 12.947$, $R^2 = 0.36$, $P < 0.001$).

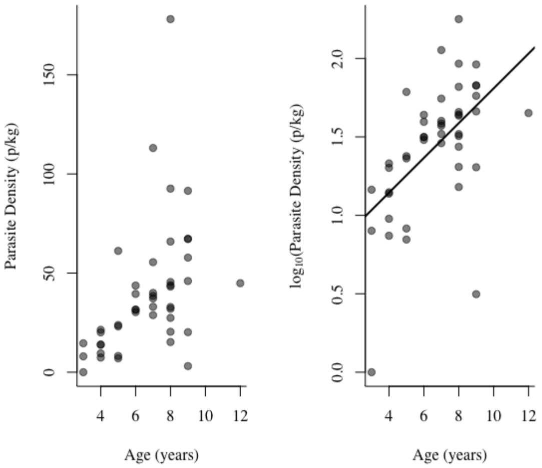

Fig. 4. (Left) The relationship between parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) and the age (years) of Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between the $\log_{10}$ transformation of parasite density ($D$) and age ($A$). A regression analysis yielded the model ($\log_{10}(D) = 0.111A + 0.701$, $R^2 = 0.30$, $P < 0.001$).

## IV. DISCUSSION

The primary finding in this study is that Cisco condition is negatively correlated with *T. crassus* infection severity. This is consistent with the findings of Miller (1945, 1952), whose studies suggest that Ciscoes infected heavily with *T. crassus* grow more slowly and are lighter when compared to less heavily infected specimens. The migration of *T. crassus* procercoids through the tissues of Cisco likely causes significant trauma to the fish. This necessitates metabolically costly immune responses and can reduce the host's lipid content (Timi and Poulin 2020). The preoccupation of the immune system with *T. crassus* leaves Cisco more vulnerable to other environmental or pathogenic stressors. The degradation of host condition and growth is an effect that has been documented in other fish tapeworms. It has been suggested that this is beneficial to the parasite as it increases the chance that the intermediate host is consumed by the definitive host (Barber et al. 2000).

A secondary finding is that percent dry fillet weight is significantly correlated with relative weight. This is supported by previous studies, which have found strong correlations between condition indices and lipid content in Ciscoes (Pangle and Sutton 2005). Some of the variation observed could be explained by inconsistency in filleting. Ciscoes, as with other Salmonids, do not store lipids homogenously throughout their muscular tissues. One area of high lipid concentration is directly beneath the skin. This could potentially cause variability since standard filleting is often inconsistent in the amount of tissue left on the skin.

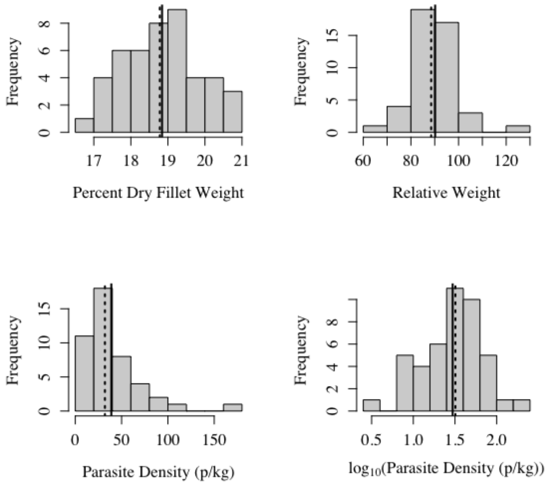

Fig. 5. These histograms show the distributions of percent dry fillet weight, relative weight, parasite density (*Triaenophorus crassus* cysts per kilogram of fillet weight, or p/kg), and the $\log_{10}$ transformation of parasite density for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. Mean is represented as a solid line, and median is displayed as a dotted line.

The severity of *T. crassus* infection was also significantly correlated with age. The trend has also been observed in previous studies. Miller (1952) found that *T. crassus* cyst abundance increases steadily from year 2 to 7 before stagnating or decreasing. This is attributed to the lifespan of *T. crassus* plerocercoids, which was estimated to be between 4 and 5 years. This was similar to what was observed in this study, though the age at highest abundance was slightly higher. This may be due to ecological differences between Lake Bemidji and the lakes studied by Miller (1952).

Prevalence of *T. crassus* in Ciscoes sampled in this study was high. The highest infection prevalence found by Miller (1952) was 93%. This may show that *T. crassus* is very successful in Lake Bemidji. Whether or not this is exceptional for lakes in Northwestern Minnesota is not yet known. An assessment of *T. crassus* prevalence in Ciscoes from other systems in the region would provide a more meaningful reference for this statistic.

The densities and abundances of *T. crassus* cysts observed in this study were highly variable. This is consistent with the findings of Miller (1952). Average abundances were the same as those observed in Ciscoes by Miller (1945) in Lesser Slave Lake ($\mu = 9$ cysts per fish). The range of ages in sampled Ciscoes could be a major cause of variability in infection severity. Another source could be individual feeding differences during spring and early summer, when *T. crassus* infested prey may be concentrated in shallow water. The variability of infection severity observed in this study is consistent with the findings of Miller (1952).

Another finding is that the relative weight of Ciscoes in Lake Bemidji is variable. The correlation between infection severity and relative weight may suggest that any variability in the former would cause the same effect in the latter. This could explain the wide range of relative weights observed in this study.

An important note in this study is that Ciscoes exhibit relatively high morphological diversity. This can induce variation in the effectiveness of standard weight equations in comparing specimens. This is most applicable when comparing Ciscoes from separate systems. A predictor of average relative weight is the fertility of the system. Populations in oligotrophic systems exhibit a lower average relative weight than those in mesotrophic systems. The standard weight equation used accounted for inland lakes including both oligotrophic and mesotrophic systems (Fisher and Fielder 1998). Because oligotrophic systems are included in the equation’s development, condition estimates for Ciscoes in mesotrophic lakes will be higher than is accurate. This could potentially explain why the condition estimates are relatively high for the specimens used in this study.

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# APPENDIX A

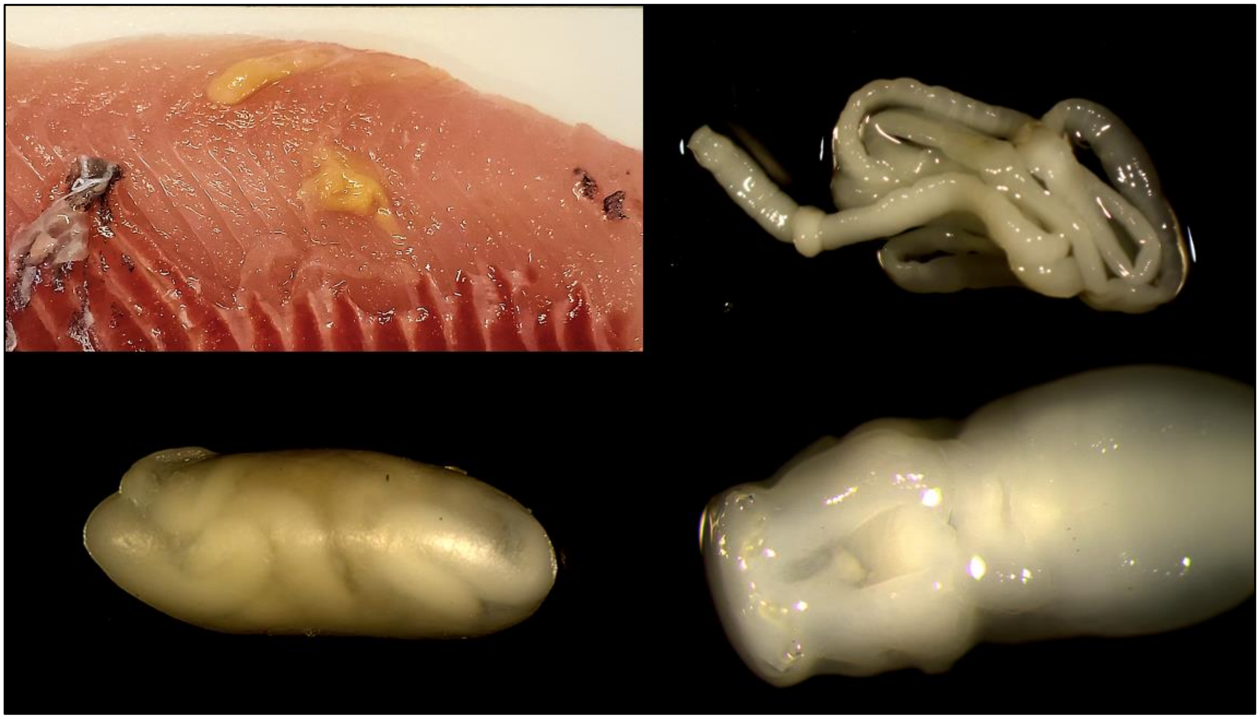

Figure A1: (Top-Left) Cysts of *Triaenophorus crassus* in the flesh of a Cisco *Coregonus artedi*. (Bottom-Left) A plerocercoid of *T. crassus* contained in a cyst. (Top-Right) A plerocercoid of *T. crassus*. (Bottom-Right) The scolex of a *T. crassus* plerocercoid. Each plerocercoid shown was found in Cisco specimens that were captured from Lake Bemidji in January and February 2024.