Diet, parasites, and potential effects of parasite infection abundance on health of Arctic cisco from Shingle Point, Yukon

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2026

DIET, PARASITES, AND POTENTIAL EFFECTS OF PARASITE INFECTION ABUNDANCE ON HEALTH OF ARCTIC CISCO FROM SHINGLE POINT, YUKON

by

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ABSTRACT

Johnson, M.W., Brewster, J.D., Gruben, M., Stairs, C., Gallagher, C.P., Loseto, L.L. 2026. Diet, parasites, and potential effects of parasite infection abundance on health of Arctic cisco from Shingle Point, Yukon. Can. Tech. Rep. Fish. Aquat. Sci. 3823: vii + 60 p. https://doi.org/10.60825/7vmz-1175

Concerns from Inuvialuit harvesters regarding parasites in Arctic cisco (*Coregonus autumnalis*) harvested at Shingle Point (Tapqaq), Yukon, and nearby coastal areas, along with monitoring priorities within the Tarium Niryutait Marine Protected Area, prompted an assessment of parasite abundance and fish condition. Whole Arctic cisco collected in 2021 (n = 20) and 2022 (n = 12) were examined to determine parasite prevalence, intensity, and abundance. Stomach contents were analyzed, and relationships among parasite abundance, body condition, and sex were explored.

Ten of the 32 fish had empty stomachs. A total of 25 prey taxa were identified in 2021 and 15 in 2022, with planktonic calanoid copepods comprising the majority of diet items in both years. In 2021, 3,441 parasites representing 14 taxa were recorded, while 699 parasites from 17 taxa were identified in 2022. The trematode *Brachyphallus crenatus* was the most prevalent parasite species. Other commonly occurring taxa included *Dibothriocephalus* sp., *Bothrimonus sturionis*, and *Echinorhynchus salmonis*. Although all sampled fish were infected with at least one parasite taxon, parasite burdens showed little apparent effect on fish condition.

These results provide baseline information for future studies on parasite dynamics, climate-related changes in parasite abundance, effects on fish health, and implications for Inuvialuit subsistence harvesting.

RÉSUMÉ

Johnson, M.W., Brewster, J.D., Gruben, M., Stairs, C., Gallagher, C.P., Loseto, L.L. 2026. Diet, parasites, and potential effects of parasite infection abundance on health of Arctic cisco from Shingle Point, Yukon. Can. Tech. Rep. Fish. Aquat. Sci. 3823: vii + 60 p.
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Les préoccupations des pêcheurs Inuvialuits concernant les parasites du cisco arctique (*Coregonus autumnalis*) récolté à Shingle Point (Tapqaq), au Yukon, et dans les zones côtières voisines, ainsi que les priorités de surveillance dans la zone de protection marine de Tarium Niryutait, ont mené à une évaluation de l'abondance des parasites et de la condition des poissons. Des ciscos arctiques entiers prélevés en 2021 (n = 20) et en 2022 (n = 12) ont été examinés pour déterminer la prévalence, l'intensité et l'abondance des parasites. Les contenus stomacaux ont été analysés et les relations entre l'abondance des parasites, la condition corporelle et le sexe ont été explorées.

Dix des 32 poissons avaient l'estomac vide. Au total, 25 différents taxons de proies ont été identifiés en 2021 et 15 en 2022. Les copépodes calanoïdes planctoniques constituaient la majorité des éléments alimentaires au cours de ces deux années. En 2021, 3 441 parasites représentant 14 taxons ont été recensés, tandis que 699 parasites de 17 taxons ont été identifiés en 2022. Le trématode *Brachyphallus crenatus* était l'espèce de parasite la plus commune. Parmi les autres taxons commun, citons *Dibothriocephalus* sp., *Bothrimonus sturionis* et *Echinorhynchus salmonis*. Bien que tous les poissons échantillonnés aient été infectés par au moins un taxon parasitaire, les charges parasitaires ont eu peu d'effet apparent sur la condition des poissons.

Ces résultats fournissent des renseignements de base pour les études futures sur la dynamique des parasites, les changements liés au climat dans l'abondance des parasites, les effets sur la santé des poissons et les répercussions sur la récolte de subsistance des Inuvialuit.

INTRODUCTION

CONTEXT

Over the years there has been increased concern from Inuvialuit harvesters regarding parasites observed in Arctic cisco, *Coregonus autumnalis* (Pallas, 1776), caught at Shingle Point (Tapqaq), Yukon, Canada and other nearby coastal areas. Harvesters report increased observations of parasites affecting fish condition, which, in turn, have had an impact on the desired quality of flesh preferred for consumption. We conducted a study to identify and enumerate parasite species in Arctic cisco harvested at Shingle Point, evaluate potential impacts to fish by examining relationships between parasite abundance and fish host health metrics.

PARASITES AND FISH HEALTH

The parasite fauna of anadromous Arctic cisco in the Canadian Arctic has not been extensively studied, particularly in recent decades. The diversity of parasite component communities from Arctic cisco from the North American Arctic has historically been low compared with most other coregonines, particularly non-anadromous populations (Watson and Dick 1979; Haldorson 1984; West 1986; McDonald and Margolis 1995; Stewart and Bernier 1999; Polyaeva 2021). In seasonal sampling of Alaskan Arctic coastal waters, Haldorson (1984) found only three parasite species in Arctic cisco, and one of these, *Bothrimonus sturionis,* was only observed during summer. A broader summary of some common parasites observed in Arctic freshwater and anadromous fish species from the Northwest Territories and Nunavut reported a total of six genera: one copepod (*Salmincola* sp.), three cestodes (*Dibothriocephalus* sp*., Bothrimonus* sp*.,* and *Proteocephalus* sp.), one trematode (*Brachyphallus* sp.), and one acanthocephalan (*Echinorhynchus* sp.) in Arctic cisco (Stewart and Bernier 1999). Neither Haldorson (1984) nor Stewart and Bernier (1999) identified parasites encysted in Arctic cisco muscle.

Although rarely studied in such contexts, parasites are important components of ecosystems in terms of both biodiversity and food web connectedness and can account for a substantial portion of the biomass (Marcogliese 2001; Kuris et al. 2008; Lafferty 2008; Lõhmus and Björklund 2015; Byers 2021). Fish and their parasite communities have co-evolved over time to reach a balance in healthy ecosystems. The parasites are a reflection of the interactions of fish hosts with other biotic components, including invertebrates (benthic and planktonic) and other fish species.

Lafferty et al. (2006) estimated that up to 78% of food web linkages involved parasites. Their potential influences on predator-prey relationships can help strengthen ecosystems. For example, the trematode *Euhaplorchis californiensis*, infects the brains of killifish (*Fundulus parvipinnis*) in California salt marshes and alters its behaviour so that it becomes significantly more likely to be preyed upon by the definitive host birds (Lafferty 2008). Free-living stages of some parasites can also be food for other invertebrates and fish.

There are also complex interrelationships between the host and its parasite community and between parasites within the same host that influence transmission, growth, survival and life history strategies of parasites (Pedersen and Fenton 2007; Lagrue and Poulin 2008; Alizon et al. 2013; Friesen et al. 2017). The interactions between and among parasite taxa sharing the same intermediate or definitive host can have important effects on host fitness and also create selection pressures that drive parasite evolution (Alizon et al. 2013). Pedersen and Fenton (2007) identified a parasite infracommunity network that includes: (1) host resources – the component of the host that sustains the parasite in the form of food and/or physical space with each parasite potentially affected by the resource depletion or host damage caused by other parasites; (2) parasite community – divided into niches or guilds that share similar habitat, resource use requirements and host immune responses; and (3) host immune system – interpreted as a predator (immune system) – prey (parasite) model. The interactions between these within-host trophic levels are complex but important for identifying host-parasite relationships and how those might be affected by environmental stressors and vice versa. Low levels of relatedness among parasites competing for the same host resources generally favours more virulent phenotypes (Alizon et al. 2013). Lagrue and Poulin (2008) suggested that helminths that have different definitive hosts are expected to have negative associations when sharing space and resources within the second intermediate host, while those that share a definitive host would show positive associations. Lagrue and Poulin (2008) studied the inter and intraspecific interactions of three parasites that use the same amphipod, *Paracalliope fluviatilis*, as an intermediate host, in a New Zealand lake. A progenetic trematode that infects fish as an adult, *Coitocaecum parvum*, showed a higher proportion of progenesis when sharing a host with a bird trematode, *Microphallus* sp. than other relationships (alone or with the acanthocephalan *Acanthocephalus galaxii*). The species also showed reduced overall progenesis and reduced growth and egg production in progenetic individuals when there was intraspecific competition.

Up to six metacercariae infected the haemocoel of the same host amphipod, filling its body cavity and creating competition for limited resources. Progenetic individuals were larger than non-progenetic and this would likely increase intraspecific competition (Lagrue and Poulin 2008). The within-host effects of parasites can be highly variable and dependent not only on the parasite taxa in a multi-species infection, but also the host (Friesen et al. 2017). Understanding the effects of parasites on ecosystem dynamics requires an understanding of these complex interactions. Friesen et al. (2017) studied the effects of four parasite species (two trematodes, one acanthocephalan and one nematode) infecting three intermediate invertebrate hosts (two amphipods and one isopod) that compete for similar resources. The researchers observed that the survival of one amphipod species infected with one or both trematodes was negatively affected, while the other amphipod species was not affected. The isopod host was more active with heavy infections of one trematode while one of the amphipods moved greater distances with fewer parasites. Overall, multiple parasite taxa in a single host appeared to have an antagonistic effect on each other with a net neutral effect on the host (Friesen et al. 2017).

Due to these and other complex relationships among parasites and between parasites and hosts, studying the impacts of any parasite on host health can be challenging. Negative impacts to host health can result from changes to the parasite community (e.g., composition, abundance, virulence) but understanding how those changes to the community have occurred is equally important. For example, parasites can increase host susceptibility to contaminants, but conversely fish weakened by contamination may be more susceptible to parasitic infection (Landsberg et al. 1998). Some of these complexities are discussed in the following sections.

Parasites as Stressors

Parasites can act as stressors (Pinky et al. 2012), triggering host immune responses (Dezfuli et al. 2008; Simkova et al. 2008; Shareef and Abidi 2015), which have the potential to impact host condition factor, growth, survival, and reproduction (Bryan and Luca 2004; Harrod and Griffiths 2005a, b; Voutilainen et al. 2010). The physiologic response of hosts to parasite infection varies among host species, parasite species and strain, infection site, age, co-infections, host genetics (differences between individuals of the same host species), and infection/infestation intensity. Some examples are provided in the following paragraphs.

Encysted *Dibothriocephalus* plerocercoid larvae can be long-lived in fish intermediate hosts and can cause necrosis, and rarely at very high infection intensities, cause death of the host (Weiland and Myers 1989; Scholz et al. 2021). Infections of this intensity are more typical in lacustrine Arctic Char, *Salvelinus alpinus* (Linnaeus, 1758), where cannibalism can amplify cyst accumulation (> 5,000 cysts per host) and due to the ability of plerocercoids to re-encyst in a new viable fish host after the original host has been eaten (Stewart and Bernier 1999). *Triaenophorus crassus* plerocercoids, which encyst in the muscle of many salmonid species and mature in the intestine of Northern Pike (*Esox lucius*), can damage internal organs of the intermediate fish host as they emerge from ingested copepods and penetrate fish host organs as they migrate from the stomach to the muscle (Stewart and Bernier 1999). Plerocercoids of *Ligula intestinalis*, were linked to changes in behaviour of Roach, *Rutilus rutilus* Linnaeus, 1758 (Loot et al. 2001). Heavily infected roach were found closer to the shoreline where they were more likely to encounter piscivorous birds, the definitive hosts for *Ligula intestinalis* (Loot et al. 2001). Similar behavioural changes where the host becomes more susceptible to bird predation have been reported for Threespine Stickleback, *Gasterosteus aculeatus* Linnaeus, 1758, infected with plerocercoids of the tapeworm *Schistocephalus solidus* (Barber et al. 2004).

At intensities of less than 30, some acanthocephalans in the genus *Echinorhynchus* have demonstrated little effect in coregonines but have been shown to negatively impact fish health at intensities of over 250 per fish (Bauer 1970). Other acanthocephalans have produced inflammatory responses at the site of infection in Brown Trout, *Salmo trutta* Linnaeus, 1758, (Dezfuli et al. 2008). High densities of cysts of the nematode, *Raphidascaris acus,* in the livers of small, juvenile Yellow Perch (*Perca flavescens* Mitchill) were associated with a reduction in visceral fat mass, which could negatively affect overwinter survival (Johnson and Dick 2001). Infection intensity of the monogenean *Gyrodactylus* spp. on the gills has been found to have a negative relationship with body condition of the fish host in a study of experimentally infected Threespine Stickleback (Anaya-Rojas et al. 2016). The authors also found that infections of this parasite can significantly affect host resistance to additional infections and cause dietary shifts from insect nymphs to copepods. Heavy *Salmincola* spp. infections can lead to secondary infections to the gills, skin, and/or fins at the site of attachment (Stewart and Bernier 1999). Some trematodes have also been reported to affect fish health, particularly during their metacercaria life cycle stage when they often encyst in host tissues. For example, *Diplostomum*

spp. flukes infect the eyes of many fish species. In Arctic Char they have been shown to cause mechanical disengagement of the retina (Padros et al. 2018) and lower growth rates, possibly via effects to energy metabolism (Voutilainen et al. 2010). Observed effects of *Diplostomum* spp. in European Whitefish, *Coregonus lavaretus,* included a reduction in fish weight when parasite-induced cataracts reached 100% in both eyes (Karvonen and Seppala 2008). *Apophallus brevis* metacercariae in the musculature of Yellow Perch in Canadian Shield Lakes decreased growth rates and caused mortality in younger fish (Johnson and Dick 2001). *Euclinostomum heterostomum* metacercaria infections caused several histopathologic effects to the liver and kidneys of the Spotted Snakehead, *Channa punctata*, in India (Shareef and Abidi 2015). Fish heavily infected with metacercaria of *Tetracotyle wayandensis* showed sluggish movements and reduced appetite and necrosis of oocytes in the ovaries of females (Jithila et al. 2021). Heavy infections of *Ichthyocotylurus erraticus* metacercariae in pericardial cavities of Irish populations of Arctic cisco resulted in reduced food intake, condition and liver size of males, but increased condition in females, and decreased gonad mass in both sexes (Harrod and Griffiths 2005a, b). Infection intensity of *I. erraticus* in cisco also increased with fish age.

Effect of Stressors on Parasites

On the other hand, parasite communities within an ecosystem can also be an important indicator of environmental changes or stressors affecting the ecosystem. A number of reviews have summarized the effects of various stressors on parasites (Landsberg et al. 1998; Lafferty and Kuris 1999; Marcogliese 2001, 2008, 2016; Thomas et al. 2005; Lafferty 2008; Vidal-Martinez et al. 2009; Wood et al. 2010; Lõhmus and Björklund 2015; Byers 2021; Sures and Nachev 2022; Grabner et al. 2023; Sures et al. 2023). Stressors include, but are not limited to: changes to water temperature and oxygen levels, extreme weather events, ocean acidification, ice cover, UV light penetration, eutrophication, changes to water levels and flow rates, changes to salinity, pollutants and fisheries. The interactions are complex and effects on parasites are taxon-specific and can be direct or indirect, negative or positive and challenging to predict (Marcogliese 2001; 2008, 2016; Sures et al. 2023). Parasites and/or intermediate invertebrate hosts may be more sensitive to environmental stressors than the fish host and parasite responses to stressors can be highly variable. Parasites with complex life cycles involving several stages and host species (heteroxenous) can be particularly susceptible to negative environmental impacts, if even one life

stage or host species is affected, while the opposite may be true for parasites with simple (monoxenous) life cycles (Landsberg et al. 1998; Sures et al. 2023). Similarly, if a parasite host is more tolerant of a particular stressor it may increase in abundance at the expense of less tolerant species, thus potentially increasing transmission rates of its parasites. Specialist parasites are also more likely to experience negative effects from stressors than generalist ones (Sures et al. 2023). A review by Sures et al. (2023) concluded that parasite richness is low and total abundance high in stressed ecosystems while richness is high and abundance low in ecosystems that are not stressed.

Different parasite taxa respond differently to the various environmental stressors. The general consensus is that there will be strong multifactorial effects of climate change on parasites within an ecosystem (Lõhmus and Björklund 2015). Vidal-Martinez et al. (2009) summarized data from 52 field and experimental studies, covering a wide range of potential stressors, conducted from 1997-2008 and found that protozoans/myxozoans and acanthocephalans are more likely to have a positive interaction with an environmental stressor while digeneans and crustaceans are more likely to have a negative interaction. Of all the potential stressors, the effects of water temperature increases have received the most focus from researchers (Marcogliese 2001, 2008, 2016; Lafferty 2008; Lõhmus and Björklund 2015; Byers 2021). Increased temperatures are often predicted to enhance parasite growth and transmission, but can also exceed thresholds for some species, resulting in negative impacts to the parasite. Increases in temperature can accelerate growth rates of the hosts and facilitate more rapid completion of parasite life cycles, resulting in the production of more generations and greater transmission rates of parasites each year within the northern regions of North America (Marcogliese 2001, 2008; Lõhmus and Björklund 2015). Many fish diseases have shown increased virulence and transmission in higher water temperatures, including bacteria, cestodes, myxozoans, and trematodes in a variety of host fish species, including many salmonids (e.g., whirling disease, black spot; Marcogliese 2008). Parasites with fewer stages are more likely to benefit more from increased temperatures that increase their growth and maturation rates. Parasites with complex life cycles may experience some benefit from increased temperatures to a certain extent (Marcogliese 2001, 2008; 2016), but the overall effect may be negative. For example, a recent study examining the parasite abundance in eight fish species in Puget Sound from 1880-2019 found that parasites with more complex life cycles (i.e., three or more hosts) declined in abundance at a rate of almost 11% per

decade or 38% for every 1°C increase in sea surface temperature (Wood et al. 2023). Parasites with fewer hosts showed no change in abundance. Although changes in temperature appear to be the driving force in this significant loss of parasite biodiversity, other factors are likely also contributing (Wood et al. 2023). The cercarial stages of some digeneans can have a prolonged transmission period (e.g., through winter) from the snail first intermediate to a fish second intermediate host when water temperatures are higher. However, transmission can also be interrupted if temperature increases are too high and upper thermal thresholds are reached, either for a parasite taxon at some point in its life cycle or for one of its host species. Higher water temperatures can also increase stress in fish, particularly cold-adapted species (Marcogliese 2001). Increases in stress can make a fish more susceptible to infection and a greater risk of pathology associated with infection (Marcogliese 2001; Lõhmus and Björklund 2015; Byers 2021). Greater pathology in a fish or invertebrate host can interrupt the parasite's life cycle, negatively affecting the population (Lõhmus and Björklund 2015), though some parasites can avoid this by developing progenetically in the intermediate host and skipping the definitive host. Fish behavioural responses to climate change, such as avoiding warmer areas (surface waters) in favour of cooler habitats (benthic waters) can expose them to different transmission rates of certain parasites and exposure to novel taxa that may affect host health (Lõhmus and Björklund 2015). Understanding the thermal performance curves for hosts and their parasites can help predict some of the effects of climate change on both and assist with predicting outbreaks (Byers 2021). Knowledge of the variables that influence growth and reproduction of a parasite is also important and includes prevalence, intensity, transmission, demographics, abundance, and distribution (Byers 2021). However, such information, particularly in wild populations is relatively limited. Studies on farmed salmonids may provide some insight into the potential outbreaks of some pathogens in wild populations (Byers 2021).

Changing host distributions can affect parasite distributions (Lafferty and Kuris 1999; Marcogliese 2001; Byers 2021). For example, in a review of existing information, Marcogliese (2001) estimated that 83 species of parasites (mostly monogeneans) could potentially invade the Great Lakes along with their hosts as average water temperatures increase. New fish host species can also compete with existing fish populations, altering their diets and, thus, their parasite infracommunity or introduce new parasites/diseases that may be particularly pathogenic to native populations (Lafferty and Kuris 1999; Marcogliese 2001). Many parasites have adapted their life

cycles to coincide with those of their hosts. If this synchronicity is disrupted, it could affect the life cycle of the parasite. For example, *Triaenophorus crassus* typically reaches maturity in pike in spring, releasing eggs when pike are inshore to spawn (Marcogliese 2001; Lõhmus and Björklund 2015). There, the egg hatches and the coracidium is ingested by the cyclopoid, *Diacyclops thomasi*. If a second intermediate fish host, (e.g., *Coregonus* spp.) use this same habitat during the first few months of summer for feeding on zooplankton in the productive littoral zone, they are more likely to become infected. *Philonema* spp nematodes show similar timing where the gravid females and larvae pass into the water only after the host salmonid has returned to freshwater to spawn, generally coinciding with peak abundance of cyclopoids (Marcogliese 2001; Lõhmus and Björklund 2015). If the timing of salmonid spawning is disrupted, so too is the parasite life cycle.

A reduction in water levels due to climate change is likely to increase the prevalence of many parasites, particularly those that use snails as first intermediate hosts and fish as the second (Marcogliese 2001, 2016). Winter in the boreal region usually limits parasite growth and transmission, with parasites often overwintering in intermediate hosts when definitive hosts are feeding less (fish) or emigrated from the system (e.g., birds). Reduced ice cover can increase winter productivity and parasite transmission may persist year-round. Alternatively, seals, which use sea ice for breeding, may become less common in ice-free scenarios, thus disrupting the life cycle of anisakid nematodes.

Extreme weather events (e.g., hurricanes) can cause crashes in parasite communities that may take years to recover due to food web disruptions and ecosystem-level impacts (Marcogliese 2016). Acidification can decrease survival of trematode cercariae, but transmission success to the next host can sometimes increase (Marcogliese 2016; Byers 2021). Changes in salinity can affect parasites whereby those more tolerant to higher salinity may increase under such conditions and those less tolerant may decrease and vice versa (Marcogliese 2016; Byers 2021), which can have a particularly significant effect on anadromous fish hosts.

Pollutants can either increase parasite prevalence and abundance if any of the parasite's host taxa become more susceptible to infection (e.g., reduced immune responses) or host populations increase, or they can decrease parasite populations if the parasites are more susceptible to the effects of pollutants during certain life stages than host taxa or the host taxa abundance decreases 4 virulent ectoparasites with monoxenous life cycles (e.g., monogeneans) can quickly overwhelm

vulnerable hosts such that the effects of any additional pollutants in the system would be negligible. Similarly, a sudden input of large quantities of highly toxic pollutants can cause mortality of hosts independent of any parasitic infections. Often though, parasites and pollutants will have an additive effect whereby pollutant-weakened immune systems enhances parasite pathogenicity. Antagonistic interactions include the often large capacity of certain parasite taxa to accumulate pollutants, such as metals, that acts as a buffer for the host (improving survival rates). For example, acanthocephalans have frequently been noted to bioaccumulate toxins, protecting their hosts from some of the negative health effects (Sures and Siddall 1999; Filipović et al. 2013; Molbert et al. 2020). Although, we are still a long way from fully understanding the interactions between parasites and pollutants, ignoring parasites in toxicological studies can lead to an overestimation of the effects of a toxicant on a target species. (Grabner et al. 2023). Commercial fishing can increase stress on fish already impacted by parasites but it can also remove potential hosts, lowering the overall parasite abundance to an extent that a parasite population is no longer viable (Lafferty and Kuris 1999; Thomas et al. 2005; Lafferty 2008; Wood et al. 2010). For example, prevalence of *T. crassus* in *Coregonus lavaretus* decreased in an experimentally fished population while *Dibothriocephalus ditremum* did not decrease (Amundsen and Kristoffersen 1990). The former uses Northern Pike as the definitive host, which was also experimentally fished, while the latter uses birds. Alternatively, fisheries that specifically avoid heavily parasitized fish stocks can work to intensify infection levels (Lafferty and Kuris 1999; Wood et al. 2010). Similarly, other host taxa and their parasite infracommunities within an ecosystem that are not targeted by a fishery may increase in abundance with the removal predators or competitors (Wood et al. 2010). However, the overall effect is thought to be an ongoing long-term global decline in fish parasites due to intensive industrialized fisheries that has largely been unrecognized, with the more specialized or the greater the host-specificity of a parasite, the more vulnerable it will be such impacts to its host (Wood et al. 2010).

Negative effects of parasites on their hosts can be amplified by other environmental factors. For example, Sala-Bozano et al. (2012) found that the mouth isopod, *Ceratothoa italica*, affected growth and hepatosomatic index (HSI) in an exploited population of a Mediterranean coastal fish species, while an infected population of the same species in a marine protected area appeared to be unaffected. When experimentally tested at a range of temperatures (10-22°C) Godwin et al.

(2020) observed that the negative effects of sea lice, *Lepeophtheirus salmonis,* on the health of juvenile Atlantic Salmon increased as temperature increased. Byers (2021) suggests that the number of potentially pathogenic parasites/diseases in wild populations of fish may be much greater than what has been reported as many may be latent, occurring in subclinical levels or producing so few mortalities as to go unnoticed in a population. Environmental stressors, such as those from climate change, may influence outbreaks of these pathogens. For example, mycobacteriosis was initially thought to only be a stress-induced disease of farmed fish, but it has become a source of significant mortality in wild Striped Bass (*Morone saxatilis*) in Chesapeake Bay as temperatures have increased (Groner et al 2018; Byers 2021). In an experimental exposure of four sympatric crustacean species to four parasite species at different temperatures and parasite exposure levels, Friesen et al. (2021) found that there were interactive effects between parasites and temperature that can influence ecosystem dynamics. Higher temperatures and continuous parasite exposure decreased abundances of the amphipods but not the isopods used in the study. This suggests there could be an increased abundance of isopods relative to amphipods in the community. Another experiment that exposed fish to higher temperatures and monogeneans showed that the rate of parasitism increased rapidly at the higher exposure temperature and resulted in oxidative stress to the host fish (Da Costa 2021).
The objectives of this study were to assess the diet and parasite infracommunities of Arctic cisco that were harvested from Shingle Point, Yukon to examine potential effects of parasite infections on fish health, particularly those found in the muscle, which are valued by Inuvialuit harvesters.

MATERIALS AND METHODS

STUDY AREA DESCRIPTION

Shingle Point, YT (68°57’N, 137°13’W) is an important harvesting camp within the Shallow Bay subregion of the Tarium Niryutait Marine Protected Area (TNMPA). The TNMPA boundaries encompass three sub-regions and were established with monitoring objectives around protecting beluga, marine fish species and their supporting habitat (Figure 1, DFO and FJMC 2013). The diverse range of fishes observed and harvested within this coastal marine habitat is due to the mixing of Beaufort Sea marine waters with the large freshwater inputs from the Mackenzie River Plume (Carmack and Macdonald 2002).

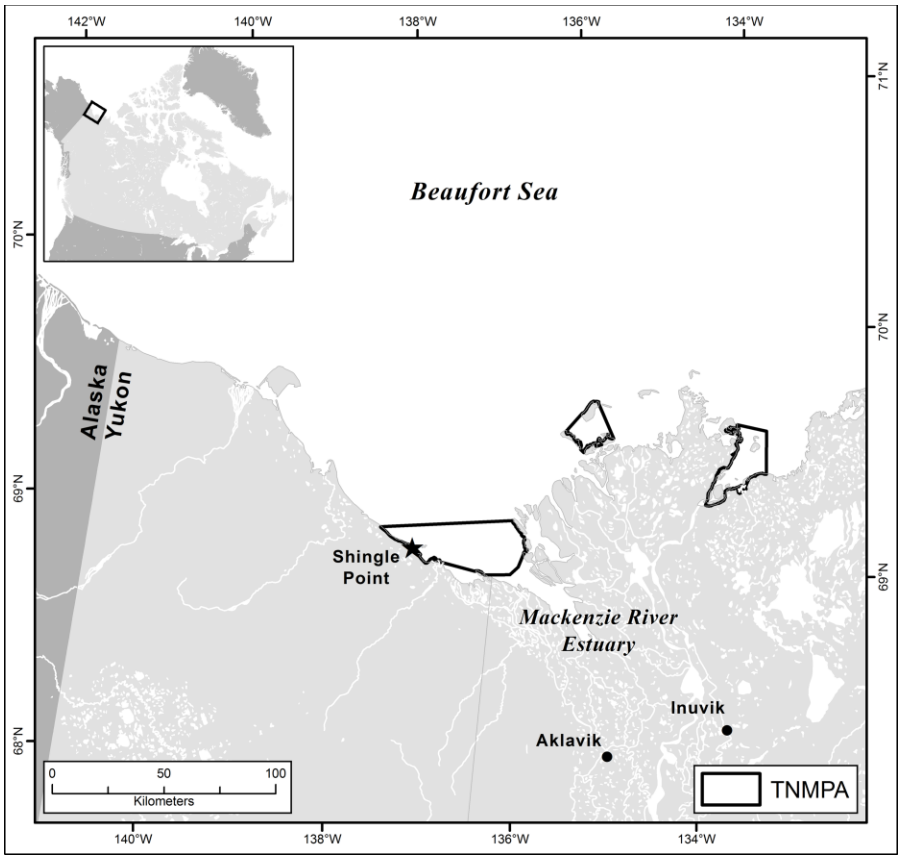


Figure 1. Map of the three sub-regions of the Tarium Niryutait Marine Protected Area (TNMPA), including the coastal habitat of Shingle Point, YT.

FISH COLLECTION

To reduce the number of Arctic cisco taken from the harvest to sample, this study was linked to an existing program, Arctic Coastal Ecosystem Study. The focus of ACES is to characterize isotopic niches and diet of fish species with different habitat use and feeding strategies (Brewster et al. 2016). Five focal species have been used as sentinels to monitor fishes that occupy the coastal environment during summer months (July-August); one of these species is Arctic cisco. Local harvesters and monitors hired through the Aklavik Hunters and Trappers Committee (HTC) collected Arctic cisco using gill and seine nets in July 2021 and 2022. Only adult individuals were used for this study based on estimated maturity of gonads and fork length (methods outlined in Brewster et al. 20162016). Whole fish samples were vacuum-sealed and kept frozen (-18°C) before being sent to North South Consultants Inc. Consulting and Freshwater Institute (Fisheries and Oceans Canada (DFO)), Winnipeg, Manitoba for processing. Samples were kept frozen prior to analyses.

FISH NECROPSIES AND DIET

Each fish was removed from the freezer and allowed to thaw sufficiently that organs could be teased apart, but still partially frozen. RoundRound weight (g) and fork length (mm) were recorded and a photo of each fish was taken prior to processing. Subsequently, the fish was examined externally under magnification for any ectoparasites on the skin, scales, and fins. Fish were carefully filleted to avoid damaging any internal organs and each fillet was thoroughly inspected under a dissecting microscope for any parasites and cysts within the musculature and subdermal tissue. All organs were removed from the body cavity and separated into individual petri dishes. The branchial and body cavities were examined for any parasites and cysts. Organs with a lumen (e.g., gastrointestinal tract, gall bladder, swim bladder etc.) were sliced open and contents scraped out with a blunt probe or small steel spatula under a dissecting microscope. Contents and organ lining were inspected for parasites and embedded cysts. Gill lamellae were examined for attached copepod and monogenean parasites. Following a surface scan, small incisions with a sharp blade were used to check the interior of liver and spleen for encysted parasites.

All parasites were enumerated, identified to the lowest taxonomic level using relevant keys (Burt and Sandeman 1969, 1974; Kabata 1969, 1988; Beverley-Burton 1984; Arai 1989; Gibson 1996; Hanzelová and Scholz 1999; Eiras 2002; Gibson et al. 2002, 2005; Kuchta et al. 2007, 2014; Arai and Smith 2016; Wagner 2016; Brabec et al. 2023; Bouguerche et al. 2024), and preserved in 70% ethanol. Parasites that could not immediately be identified to species during necropsy were cleared, stained to highlight key internal organs, and mounted on slides for more precise identification. Trematodes, cestodes, and acanthocephalans were stained for approximately 30 minutes, or until internal organs had absorbed sufficient colour, in a 70% ethanol-based carmine stain. Parasites were then removed from stain and placed briefly in an acid alcohol bath to remove excessive stain from the body wall, while leaving the organs well-stained. Subsequently, the parasites werewere flushed in 70% ethanol to remove all acid and stop the de-staining process. The specimens were then gradually transitioned, through serial stages, from 70 to 100% ethanol and cleared with methyl salicylate (to improve light transmission through tegument and visibility of the stained organs) before mounting on slides with Canada balsam. Nematoda were not stained, but were cleared in 5% glycerine-alcohol to view internal features.

Stomach contents of all Arctic cisco were analysed concurrently with parasite surveys. Once removed from the fish, total stomach weight (± 0.001 g) was recorded. The stomach was then cut open and an initial rough estimate of percent fullness (0, 25, 50, 75, 100%) was assessed visually. Contents were then removed by gentle scraping and rinsing under cold water into a 250 µm sieve, ensuring all contents from within the stomach folds were collected. The empty stomach lining weight was then recorded. Sieved contents were placed in glass petri dishes and examined under magnification. All contents were sorted to the lowest taxonomic groups possible given their state of digestion, enumerated, weighed (± 0.001 g), and stored separately in labeled Whirlpac bags and refrozen. Taxonomic identification of contents was conducted using all available up-to-date, relevant keys and materials, and photographs from previous dietary analyses compiled into a reference binder by North/South Consultants Inc.

ACES SAMPLING

Fish in this study were used for both the ACES analyses and parasite analyses. After tissues were examinedexamined for parasites, theythese were sampled followingfollowing the ACES program protocol. Sex and maturity were determined, and gonads and liver were weighed (g). A thumbnail-sized pectoral fin clip was removed from each fish and stored in a vial of nondenatured ethanol (95%) to archive for potential DNA analysis. Both otoliths were removed and placed in labeled envelopes for future ageing. Two small samples of muscle were collected and frozen in separate labelled bags for stable isotope and mercury analyses. HalfHalf of the liver (or the whole liver if small) was placed in a labeled bag and frozen. The fish were bisected to create two mirror image halves. One of these halves, plus the remaining half of the liver and half of the gonads were placed in a labeled bag and frozen for fatty acid analyses. The otherother half of fish and gonads were vacuum-sealed, frozen at -20°C for further processing and analysis at the FWI.

DATA ANALYSES

Individual diet taxa were grouped into higher taxonomic levels (e.g., Insecta, Copepoda, etc.) for analyses. Numbers and wet weights of each taxon were plotted as proportions (%) of the total abundance and weight of stomach contents. Frequency of occurrence (proportion of fish stomachs containing each diet taxon) were calculated for female and male cisco.

Standard parasitological data analyses were conducted for each fish, including prevalence (% of fish infect with each species), mean intensity (number of parasites per infected fish – excludes uninfected fish), and mean abundance (number of parasites per fish – includes uninfected fish). Kolmogorov-Smirnov (K-S) tests were run to determine if there were any significant differences (p value ≤0.05) in these three infection parameters between years and sexes. Due to small host sample size and low infection rates for most taxa, the K-S tests were limited to parasite taxa that were recovered from > 5 hosts (both years combined).

Several metrics were used to attempt to find correlations between parasite infections and fish health. Gonadosomatic index (GSI) can be used to identify potential effects to fish reproduction (Rozsa et al. 2000). Fulton's condition factor (K) and hepatosomatic index (HSI) were used as general measurements of overall fish health and growth of the liver, respectively, and can be used to predict impacts from parasitic infections. Condition factor was calculated as:

$$K = Wet\ Weight(g) \times \left(\frac{100{,}000}{Fork\ Length(mm)^3}\right)$$

To assess the physiological condition of the fish, HSI was calculated as:

$$HSI = \left(\frac{Wet\ Liver\ Weight\ (g)}{Wet\ Weight\ (g)}\right)$$

Similarly, GSI was calculated as:

$$GSI = \left(\frac{Wet\ Gonad\ Weight\ (g)}{Wet\ Weight\ (g)}\right)$$

For comparisons with fish health metrics, parasite species were grouped into total parasites, which included all taxa, and into major taxa where sufficient sample size numbers (n≥50) were identified (i.e., Trematoda, Cestoda, Acanthocephala). For the purpose of this report parasite groups with low abundance were excluded from additional analyses because of no significant relationship between parasite count to K (females: $R^2 = 0.0427$; males: $R^2 = 0.0148$). However, exploration of low abundance to inform on thresholds is suggested for future studies (see Conclusion section). Standardized residuals were calculated comparing parasite abundance (explanatory variable) with K, GSI and HSI (response variables) and used in regression analyses to examine whether residual variation in the fish health metrics could be explained by parasite abundance and to test whether the impact of parasites on these metrics differed between sexes. In addition, total parasite abundance was grouped into low (<100 parasites) and high (>100

parasites) for exploratory purposes, and a two-sample t-Test was performed to identify differences between these two groupings.

RESULTS

A total of 32 Arctic cisco (15 females, 17 males) were sampled for this study over two years (Table 1). Females were larger and had higher mean condition factor values (K), GSI, and HSI than males. Mean size of captured males was slightly larger in 2022 than in 2021, but all other metrics were similar between years (Table 1).

Table 1. Summary of biological information collected from anadromous Arctic cisco sampled at Shingle Point, Yukon in 2021 and 2022.

Metric		2021			2022			Combined		
		Females (n = 12)	Males (n = 8)	Total (n = 20)	Females (n = 3)	Males (n = 9)	Total (n = 12)	Females (n = 15)	Males (n = 17)	Total (n = 32)
Fork Length (mm)	Mean	361.8	337.6	352.1	365.3	359.6	361.0	362.5	349.2	355.4
	SD	10.8	17.2	18.0	27.6	10.2	14.9	14.2	17.5	17.2
	Range	342-380	299-354	299-380	334-386	348-375	334-386	334-386	299-375	299-386
Weight (g)	Mean	611.4	449.4	546.6	631.7	561.9	579.3	615.5	508.9	558.9
	SD	72.1	45.6	102.0	229.7	62.8	116.0	108.1	78.9	106.8
	Range	459-729	383-510	383-729	380-830	482-655	380-830	380-830	383-655	380-830
Condition Factor (K)	Mean	1.29	1.17	1.24	1.25	1.21	1.22	1.28	1.19	1.23
	SD	0.10	0.14	0.13	0.21	0.09	0.12	0.12	0.11	0.12
	Range	1.15-1.42	1.05-1.50	1.05-1.50	1.02-1.44	1.12-1.42	1.02-1.44	1.02-1.44	1.05-1.50	1.02-1.50
GSI	Mean	4.63	1.11	3.22	3.43	1.12	1.70	4.39	1.12	2.65
	SD	2.07	0.51	2.39	2.75	0.50	1.62	2.16	0.49	2.23
	Range	1.50-7.53	0.15-1.61	0.15-7.53	0.26-5.17	0.36-1.88	0.26-5.17	0.26-7.53	0.15-1.88	0.15-7.53
HSI	Mean	1.54	1.08	1.35	1.61	1.17	1.28	1.55	1.12	1.32
	SD	0.30	0.44	0.42	0.47	0.24	0.35	0.32	0.34	0.39
	Range	0.97-2.01	0.78-1.94	0.78-2.01	1.08-2.01	0.90-1.50	0.90-2.01	0.97-2.01	0.78-1.94	0.78-2.01

DIET

Ten of the 32 Arctic cisco stomachs were empty with fewer empty stomachs in 2022 (n = 3) than in 2021 (n = 7). There were 25 prey taxa identified in 2021 and 15 in 2022 (Table 2). Six taxa, mainly planktonic copepod species, were consumed in both years. Four fish had consumed a small amount of aquatic plant material, likely incidentally while ingesting other prey. Insecta (at least eight taxa) and Copepoda (at least seven taxa) were the most diverse taxonomic groups identified from Arctic cisco stomachs.

Planktonic calanoid copepods represented approximately 70% of the diet items by both number and weight in 2021 and more than 97% of the abundance and 60% of the weight in 2022 (Figures 2 and 3). The euphausiid, *Thysanoessa raschii*, accounted for most of the remaining weight in 2022. *Calanus* and *Eurytemora* were the most abundant copepod genera, but *Limnocalanus macrurus macrurus* was found in the most (n = 14) stomachs. Almost all of the unidentified calanoid copepods were highly fragmented individuals from three cisco stomachs that also contained large numbers of *C. glacialis* and *C. hyperboreus*, and, as such, were likely more of the same. Insecta represented 9% of the prey items by number and 12.2% by weight in 2021 but were nearly absent from stomachs collected in 2022. Furthermore, almost all of the consumed insects were adults of terrestrial taxa that were found in a single 2021 stomach. Ostracoda was the second most abundant taxon in 2021 but represented less than 1% of the total weight. Ostracods were found in only two stomachs in 2021 and none in 2022. The dietary category "Other" includes primarily unidentifiable digested remains combined with fish remains, and small numbers of amphipods, euphausiids, mysids, decapod zoea, and other rare taxa.

Some dietary differences were observed between years and sexes. Generally, 2022 stomachs were fuller with greater abundance and weight of prey taxa but with lower prey diversity. A greater proportion of female (73%) than male (59%) stomachs contained prey items. Mean stomach fullness, the number and weight of diet items per stomach and prey diversity, were all greater in females than males in 2021 (Table 3; Figure 4). The reverse was observed in 2022, though female sample size was small. *L. macrurus* was the most frequently occurring prey item in both males and females (Figure 4). Amphipods and insects were more commonly found in female stomachs and unidentifiable calanoids and other copepods (mostly the cyclopoid, *Cyclops scutifer*) were more frequently consumed by males.

Diet taxa included a mix of marine, brackish and freshwater organisms (Figures 5 and 6). Taxa typically found in freshwater and/or brackish habitat included all Insecta, *C. scutifer*, and some calanoid copepods (*L. macrurus macrurus* and *Eurytemora* spp.). Although Ostracoda can be found in any aquatic habitat, the specimens from this study were likely freshwater/brackish based on other contents identified from the same stomachs. Taxa typically found in marine habitat included some calanoid copepods (*Acartia clausi* and *Calanus* spp.), Hyperiidae amphipods, *Sabinea septemcarinata* zoea, and *T. raschii*). Other Copepoda were likely marine based on other contents identified from the same stomachs. Female cisco consumed a mix of freshwater/brackish and marine prey in 2021 (Figure 5). At least 50% of prey abundance in female stomachs was of probable freshwater/brackish origin in seven of the ten fish with contents. No confirmed marine taxa were found in male cisco stomachs in 2021 (Figure 5). The size range of sampled fish was relatively narrow and, as such, did not appear to correlate with predominantly freshwater/brackish or marine diets, though proportions of amphipods, mysids, and euphausiids were higher in some of the larger females in 2021. Marine diet items were less common in fish collected in 2022 (Figure 6). Only one female stomach had contents, which were exclusively freshwater/brackish calanoids. Two of eight males, the two smallest, had more than 90% of contents comprised of marine taxa. A third male stomach contained 30% marine taxa and the remainder were exclusively freshwater/brackish.

Table 2. Diet items identified from anadromous Arctic cisco stomachs collected from Shingle Point, Yukon in 2021 and 2022.

Higher Taxonomic Grouping	Diet Item	Sample Year	
		2021	2022
Ph. Mollusca			
Cl. Gastropoda			
Limacinidae	*Limacina helicina*	+	-
Ph. Arthropoda			
SbPh. Hexapoda			
Cl. Collembola	Unid. Collembola	+	-
Cl. Insecta	Unid. Insecta	+	-
O. Diptera	Unid. Diptera	+	-
Chironomidae	Unid. Chironomidae	+	+
Tipulidae	Unid. Tipulidae	-	+
O. Ephemeroptera	Unid. Ephemeroptera	+	-
O. Hemiptera	Unid. Hemiptera	+	-
Psyllinae	Unid. Psyllinae	+	-
O. Hymenoptera	Unid. Hymenoptera	+	-
Formicidae	Unid. Formicidae	+	-
SbPh. Crustacea			
Cl. Hexanauplia			
SbCl. Copepoda	Unid. Copepoda	+	-
Calanoida	Unid. Calanoida	+	+
Acartiidae	*Acartia clausi*	+	-
Calanidae	*Calanus* sp.	+	-
	Calanus glacialis	-	+
	Calanus hyperboreus	+	+
Centropagidae	*Limnocalanus macrurus*	+	+
Temoridae	*Eurytemora* sp.	-	+
	Eurytemora affinis affinis	+	+
	Eurytemora herdmani	+	-

Higher Taxonomic Grouping	Diet Item	Sample Year	
		2021	2022
	Eurytemora raboti	-	+
Cyclopoida			
Cyclopidae	*Cyclops scutifer scutifer*	-	+
Cl. Ostracoda	Unid. Ostracoda	+	-
Cl. Malacostraca			
SpO. Peracarida			
O. Amphipoda	Unid. Amphipoda	+	-
Hyperiidae	Unid. Hyperiidae	-	+
	Hyperia galba	-	+
	Themisto abyssorum	+	-
	Themisto libellula	+	-
O. Mysida			
Mysidae	*Mysis* spp. complex	+	-
	Neomysis awatschensis	-	+
SpO. Eucarida			
O. Decapoda			
Crangonidae	*Sabinea septemcarinata* zoea	-	+
O. Euphausiacea			
Euphausiidae	*Thysanoessa raschii*	+	+
Ph. Chordata			
SbPh. Vertebrata	Unid. Fish Remains	+	-

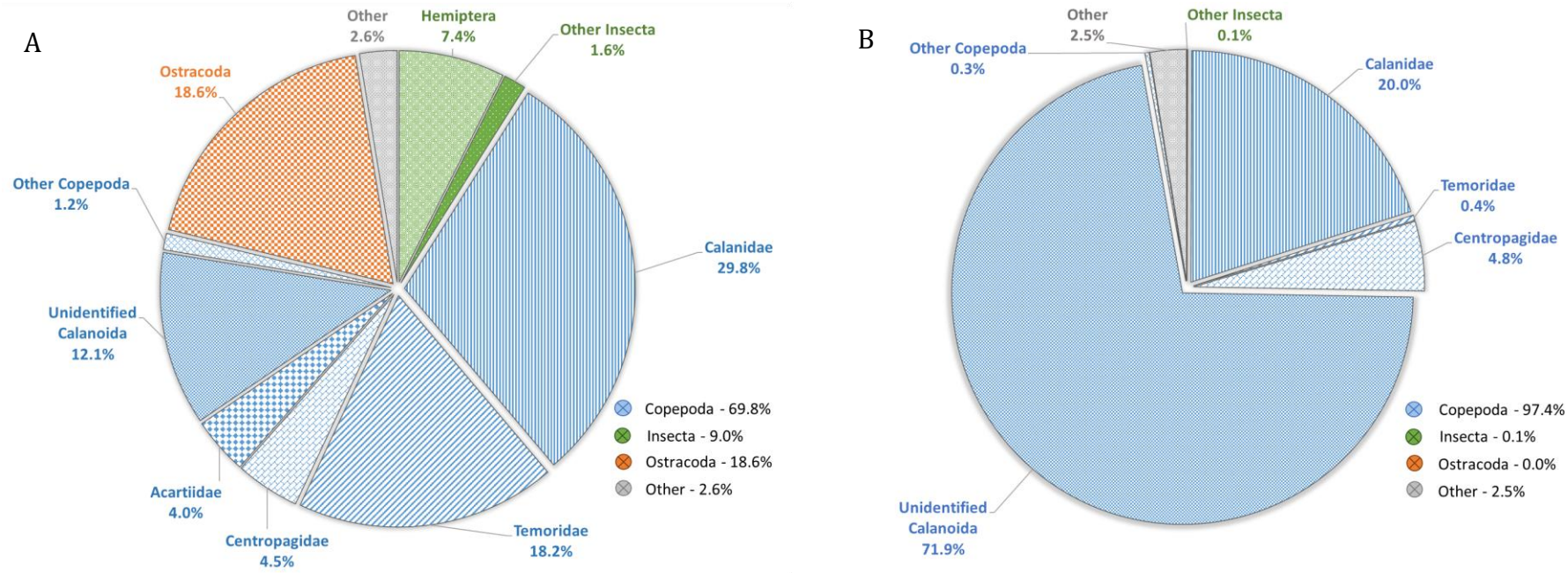


Figure 2. Proportion of diet items, by abundance, identified from anadromous Arctic cisco stomachs collected in 2021 (A) and 2022 (B) from Shingle Point, Yukon

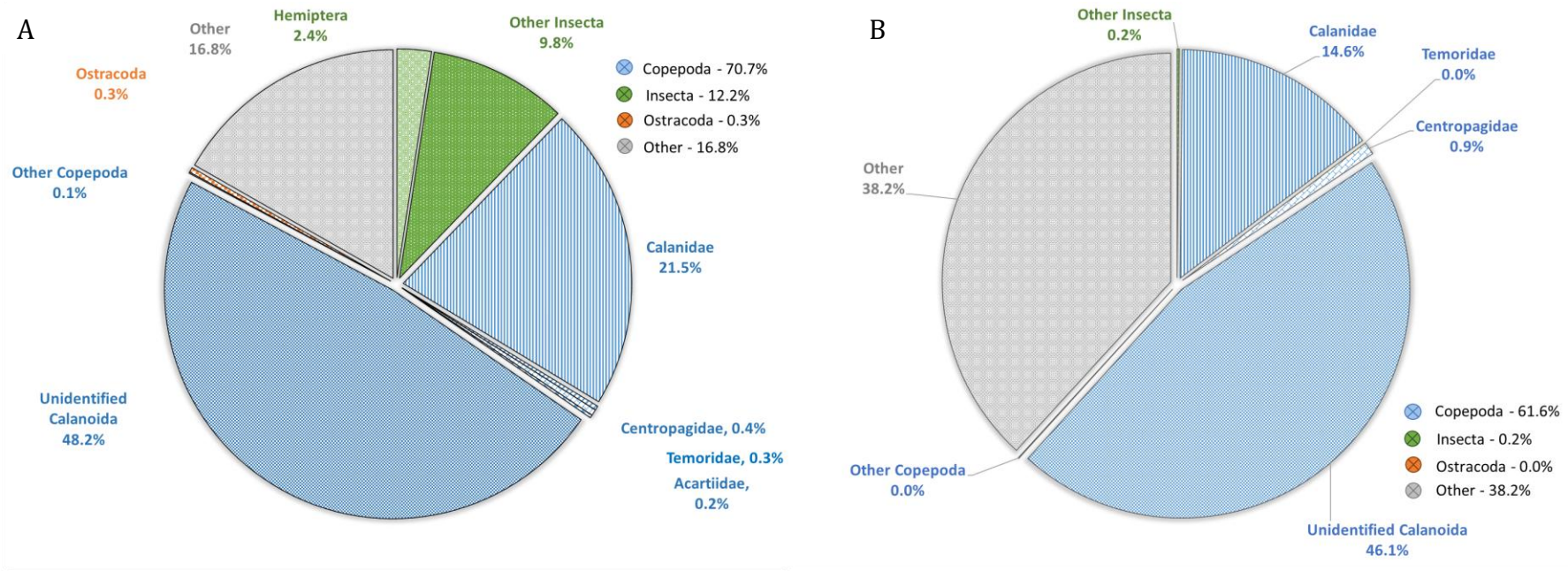


Figure 3. Proportion of diet items, by weight, identified from anadromous Arctic cisco stomachs collected in 2021 (A) and 2022 (B) from Shingle Point, Yukon.

Table 3. Summary information for stomach contents of anadromous Arctic cisco from Shingle Point sampled in 2021 and 2022.

Year		n	Stomach Fullness (%)			Diet Items per Stomach			Diet Item Weight (g) per Stomach		
			Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
2021	Females	12	33.3	26.8	0-100	53.2	121.4	0-430	0.484	1.230	0-4.324
	Males	8	12.5	18.9	0-50	39.8	110.8	0-314	0.062	0.174	0-0.494
	Total	20	25.0	25.6	0-100	47.8	114.5	0-430	0.316	0.965	0-4.324
2022	Females	3	8.3	14.4	0-25	0.7	1.2	0-2	0.000	0.001	0-0.001
	Males	9	38.9	35.6	0-100	380.2	749.6	0-1831	1.144	2.445	0-7.066
	Total	12	31.3	33.9	0-100	285.3	661.9	0-1831	0.858	2.149	0-7.066
Combined	Females	15	28.3	26.5	0-100	42.7	109.8	0-430	0.388	1.108	0-4.324
	Males	17	26.5	31.2	0-100	220.0	563.0	0-1831	0.635	1.820	0-7.066
	Total	32	27.3	28.7	0-100	136.9	420.9	0-1831	0.519	1.510	0-7.066

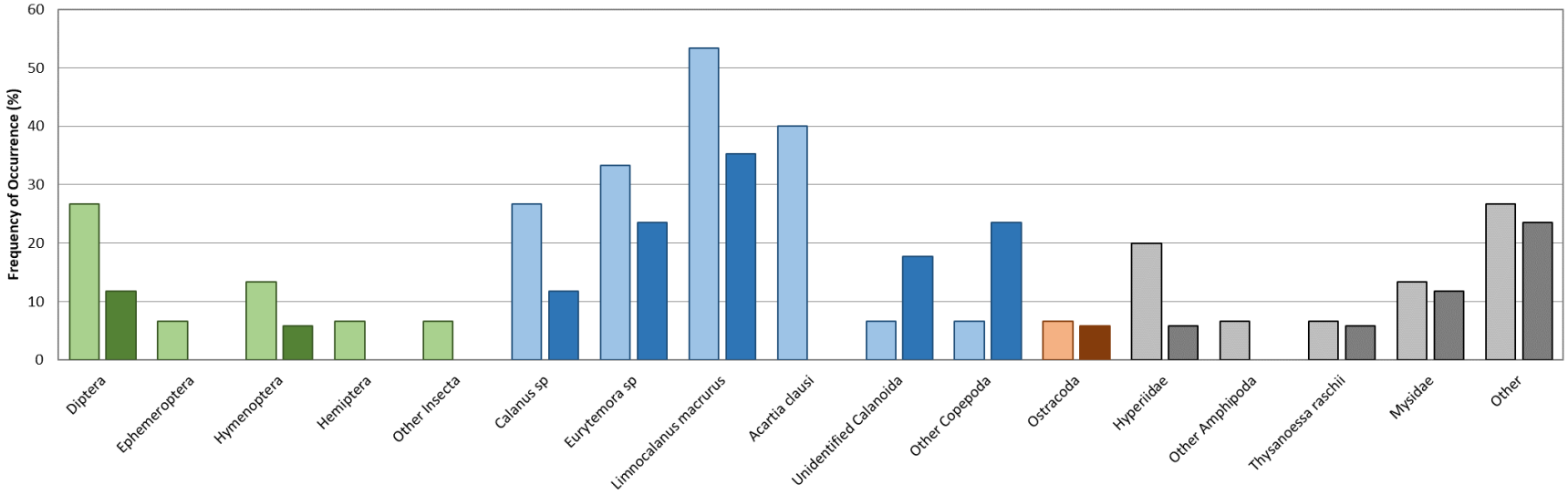


Figure 4. Frequency of occurrence of diet items in anadromous Arctic cisco stomachs sampled at Shingle Point in 2021 and 2022 (data combined). Note: lighter shaded bars of each colour are female diet items and darker shaded bars are male diet items

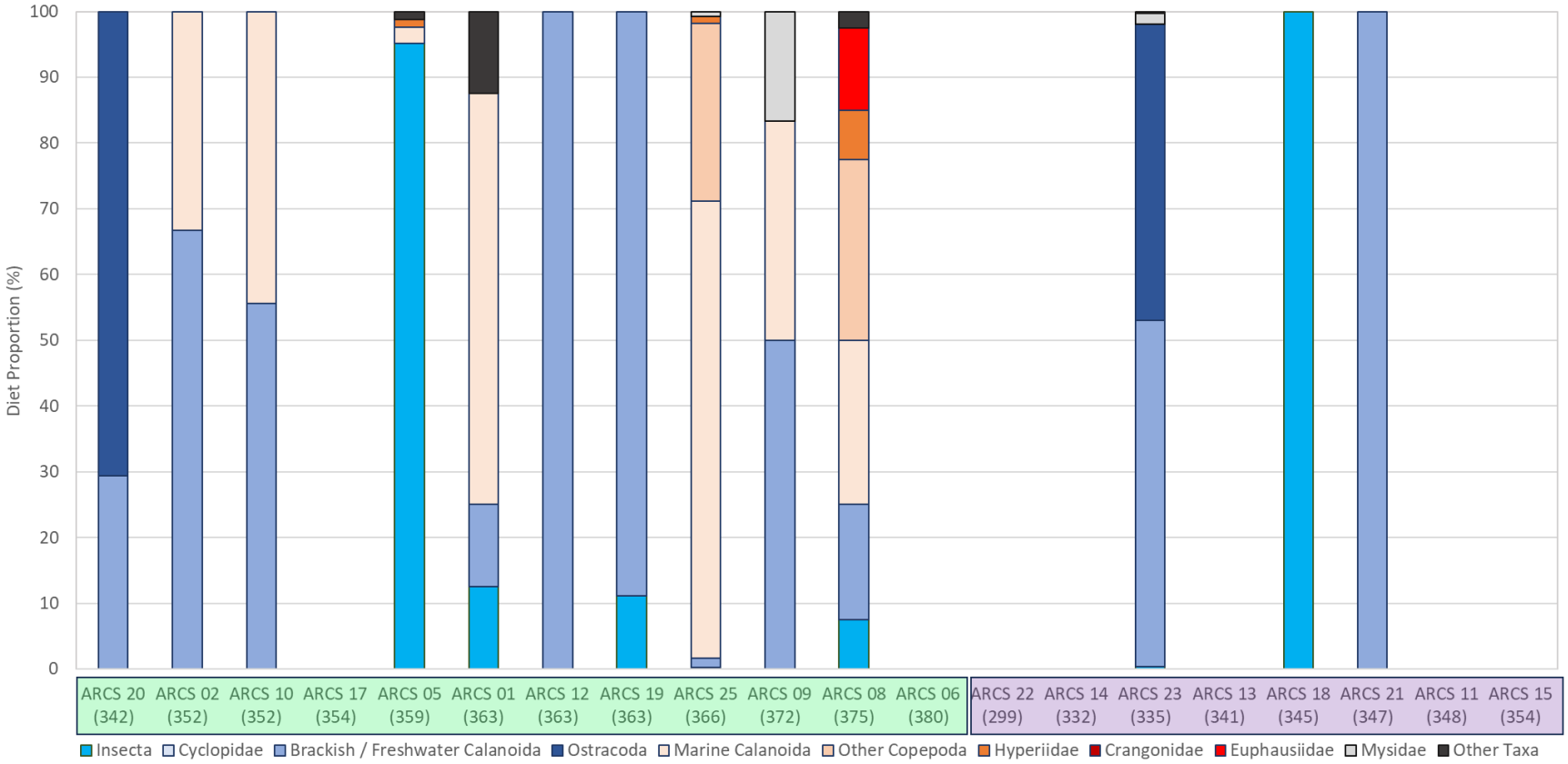


Figure 5. Frequency of occurrence (by abundance) of diet items in individual anadromous Arctic cisco stomachs sampled at Shingle Point in 2021. Shades of blue represent diet taxa primarily found in brackish or freshwater habitat. Shades of orange/red represent diet taxa primarily found in marine habitat. Mysidae and 'Other' include at least some taxa of unknown origin. Samples are arranged from smallest to largest (FL in parentheses) and separated by female (green shading) and male (purple shading) fish. Fish with no data had empty stomachs.

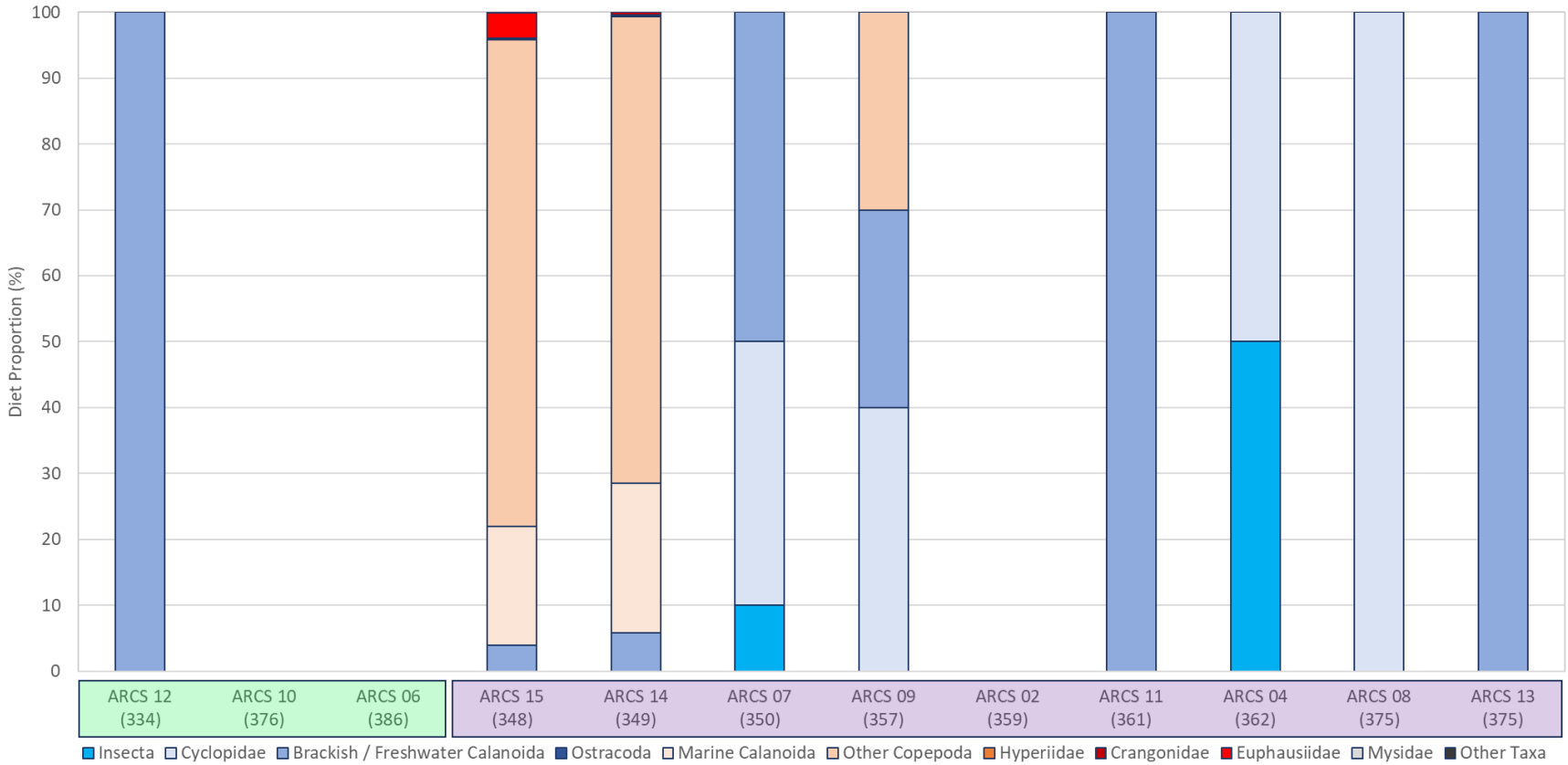


Figure 6. Frequency of occurrence (by abundance) of diet items in individual anadromous Arctic cisco stomachs sampled at Shingle Point in 2022. Shades of blue represent diet taxa primarily found in brackish or freshwater habitat. Shades of orange/red represent diet taxa primarily found in marine habitat. Mysidae and 'Other' include at least some taxa of unknown origin. Samples are arranged from smallest to largest (FL in parentheses) and separated by female (green shading) and male (purple shading) fish. Fish with no data had empty stomachs.

PARASITES

Summary information for Arctic cisco parasites by sampling year and sex are presented in tables 4 and 5, respectively. Statistical analyses comparing prevalence, mean intensity, and mean abundance between years and between female and male hosts are presented in Table 6. Although there were some observed differences in parasite community composition between years and between sexes, most were not statistically significant with small host sample sizes likely a factor. A total of 3,441 parasites from 14 taxa were collected from Arctic cisco in 2021 and another 699 representing 17 taxa were recorded in 2022. Twelve taxa were found in both sampling years (Table 4). Unidentifiable cysts (contents were damaged or crystallized) were also collected in both years. Overall mean intensity and abundance were more than three times higher in 2021 than in 2022 (Table 4), though this difference was not statistically significant (Table 6). Trematoda was the most abundant taxon and Nematoda the least abundant. The most diverse groups were acanthocephalans (minimum of four species), cestodes (four species), and trematodes (three species). The acanthocephalan *Corynosoma* sp., the cestode *Dibothriocephalus* sp., and the nematode *Anisakis simplex* use Arctic cisco (and other species) as an intermediate host and they will mature in fish-eating birds and/or mammals. The encysted *Neoechinorhynchus* sp. found in 2022 are likely *N. tumidus* that were still in the acanthella stage in the intermediate host (an ostracod) when consumed by the Arctic cisco. In this scenario the Arctic cisco may have been acting as paratenic hosts for the parasite to be transferred to a larger piscivorous fish. Other small-bodied fish species have been identified as paratenic hosts for species of *Neoechinorhynchus,* including *N. tumidus* (Abdel-Meguid et al. 1995; Kvach and Stepein 2008; Gendron and Marcogliese 2016). All other acanthocephalan species observed were or would mature in Arctic cisco.

Parasite prevalence was 100% in both males and females with all fish being infected with at least one taxon (Table 5). Males were infected with 17 different taxa, lacking only *Derogenes varicus* species complex (*D. varicus* hereafter) and *Corynosoma* sp while females were infected with 14 taxa. The trematode *Brachyphallus crenatus* was the most prevalent species in all fish. Other commonly occurring species included *Dibothriocephalus* sp. plerocercoids (both encysted on the outer surface of organs and recently digested out of intermediate hosts in the digestive tract), *Bothrimonus sturionis*, and *Echinorhynchus salmonis.* Overall mean intensity and abundance were more than five times higher in females than males, with *B. crenatus* and *B. sturionis*

accounting for much of the difference (Table 5). Both differences were statistically significant (Table 6)

Trematoda

All three of the trematode species found in Arctic cisco are marine and were likely acquired from calanoid copepod intermediate hosts (Table 5). *Brachyphallus crenatus* and *D. varicus* were found mainly in the stomach, while *Alloopistolecithum gibbosum* was found primarily in the foregut. Only one *D. varicus* specimen was found in a single female cisco in 2021. *A. gibbosum* was found in 16% of fish and was one of the more abundant parasite species. *B. crenatus* was the most prevalent and abundant of all parasite species in both years (Table 4). Overall, *B. crenatus* represented 88% of the total parasite abundance in sampled Arctic cisco. It was found in 97% of sampled fish, with a mean intensity of 117 parasites per infected fish (Table 4). Prevalence was similar between years. Although infection intensity was much lower in 2022 than 2021, the difference was not statistically significant (Tables 4 and 6). Infection intensity for *B. crenatus* was significantly higher in females than in males (Tables 5 and 6).

Cestoda

Bothrimonus sturionis was the only marine cestode found in the Arctic cisco samples (Table 5). The main site of infection was the foregut and it is typically acquired from several amphipod intermediate host taxa (Koyer 1845). It was the second-most prevalent of all cestodes (34% of fish), with the highest mean intensity (23.1 per infected fish) and was significantly more prevalent and abundant in females than males (Tables 5 and 6). There were no significant annual differences in *B. sturionis* infections. The other three cestodes were all plerocercoids. *Dibothriocephalus* sp., which are acquired from eating infected freshwater or marine copepods, were found recently digested out of copepod intermediate hosts in the stomach and intestine, and in the body cavity (within cysts) of 47% of examined fish at a relatively low mean intensity of 2.4 individuals per fish (Table 4). Prevalence was higher in 2022, but with the same number of worms per fish. More female Arctic cisco were infected than males but at a slightly lower intensity (Table 5). There were no significant differences in the infection statistics between years or sexes for *Dibothriocephalus* sp. (Table 6). Parasites in this genus mature mainly in fish-eating terrestrial mammals, including humans. *Proteocephalus* sp. specimens were generally immature and relatively uncommon in both years. *P. exiguus* is the species typically found congeners and

therefore likely the species in these Arctic cisco, however due to a lack of distinct morphological characteristics within this genus, species identification is best confirmed using molecular markers (Brabec et al. 2023). *Triaenophorus crassus* plerocercoids were found in the musculature and, in particular, subdermally in 16% of sampled fish at an overall mean intensity of 5.6 per infected fish (Table 5). This parasite primarily infects the Arctic cisco via ingestion of freshwater cyclopoid copepods and matures in Northern Pike that eat infected Arctic cisco.

Acanthocephala

The most common acanthocephalan species in Arctic cisco was *Echinorhynchus salmonis*, which was found in 34% of the sampled fish with a mean intensity of 6.5 worms per infected fish (Table 4). As with many of the parasite taxa, *E. salmonis* was more abundant in 2021 than 2022 (Table 4) but with no statistical significance (Table 6). Prevalence of this parasite was higher in females while mean intensity was higher in males (Table 5), but not significantly so (Table 6). It is typically acquired from consuming a variety of infected freshwater benthic amphipod species and was most common in the hindgut. When compared with the other species of acanthocephalans found in these fish, the proboscis of *E. salmonis* was more deeply embedded in the intestinal lining. Although typically freshwater in origin, this species can also survive in amphipods and anadromous fish using either fresh or brackish water habitats. The marine *E. gadi* was found in less than half the total hosts and at less than half the mean intensity of *E. salmonis* (Table 4). This species was more common in female Arctic cisco (Table 5). It is typically acquired when the fish host eats infected caprellid or gammarid amphipods. *Corynosoma* sp larval cystacanths were rare in both years and found exclusively in female Arctic cisco (Tables 4 and 5). These parasites typically mature in fish-eating seabirds or marine mammals and are acquired by the paratenic fish host most often from infected *Monoporeia affinis* amphipods but can also be found in a variety of the other benthic Peracaridan intermediate hosts. *Neoechinorhynchus tumidus* is a freshwater acanthocephalan that uses ostracods as an intermediate host. Infection rates for *N. tumidus* were similar between years and they were more prevalent in female Artic Cisco (Tables 4 and 5). The single *Echinorhynchus* sp. collected in 2022 was an immature specimen in poor condition that could not be confirmed as either *E. gadi* or *E. salmonis*.

Other Parasites

All remaining parasite taxa from sampled Arctic cisco were uncommon with mostly low prevalence and mean intensity (Tables 4 and 5). The myxozoan, *Henneguya* sp., was found in small, whitish, ovoid trophozooites (cyst-like stage) located subdermally in one male captured in 2022. Each of the trophozooites contained many hundreds of individual *Henneguya* sp. The life cycles of many *Henneguya* species are poorly understood, but they are generally thought to directly infect the target tissue as amoeboid sporoplasms. Morphologically, the *Henneguya* sp. recovered from sampled Arctic cisco most closely resembles *H. zschokkei* (Eiras 2002; Wagner 2016), a species known to infect other Coregonines, however, it is very difficult to confirm any myxosporean species solely using morphometrics and sites of infection within the host (Molnár et al. 2002). Particularly given this appears to be the first record of this parasite taxon in this host, genetic verification would be required to confirm the species identification.

Similarly, the monogenean, *Discocotyle sagittata*, and the copepod, *Salmincola extensus*, both infect their fish hosts directly as free-swimming larval forms and both are freshwater with variable salinity tolerances.

Nematodes were particularly rare in sampled Arctic cisco. Small numbers of cysts containing larval nematodes were found in both survey years and both sexes (Tables 4 and 5). A single nematode from the *Anisakis simplex* complex was found encysted in the muscle of an Arctic cisco captured in 2021. A single, larval *Hysterothylacium* sp. was found in the foregut in each of two male Arctic cisco in 2022. In addition, there were small numbers of unidentifiable cysts found in the musculature of Arctic cisco in both years that may have been nematodes. The cysts were dissected but contained only what appeared to be crystallized tissue. If these were parasites then they either died or were destroyed by the host immune system.

Table 4. Summary information for parasites collected from anadromous Arctic cisco sampled at Shingle Point, Yukon, 2021 and 2022.

Parasite Taxon	2021 (n = 20)			2022 (n = 12)			Years Combined (n = 32)		
	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
Myxozoa									
Henneguya sp. [1]	0.0	-	-	8.3	15.0	1.3	3.1	15.0	0.5
Trematoda									
Brachyphallus crenatus	100.0	160.1	160.1	91.7	39.3	36.0	96.9	117.2	113.5
Derogenes varicus complex[1]	5.0	1.0	0.1	0.0	-	-	3.1	1.0	<0.1
Alloopistolecithum gibbosum [1,2]	10.0	11.5	1.2	25.0	4.0	1.0	15.6	7.0	1.1
Monogenea									
Discocotyle sagittata [1]	5.0	2.0	0.1	8.3	1.0	0.1	6.3	1.5	0.1
Cestoda									
Bothrimonus sturionis	35.0	10.1	3.55	33.3	45.8	15.3	34.4	23.1	7.9
Dibothriocephalus sp. plerocercoids	40.0	2.4	0.95	58.3	2.4	1.4	46.9	2.4	1.1
Proteocephalus sp. immature	5.0	1.0	0.05	8.3	4.0	0.3	6.3	2.5	0.2
Triaenophorus crassus plerocercoids [1]	15.0	8.7	1.3	16.7	1.0	0.2	15.6	5.6	0.9
Nematoda									

Parasite Taxon	2021 (n = 20)			2022 (n = 12)			Years Combined (n = 32)		
	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
Nematoda unidentified	0.0	-	-	16.7	1.0	0.2	6.3	1.0	0.1
Anisakis simplex complex L3	5.0	1.0	0.05	0.0	-	-	3.1	1.0	<0.01
Hysterothylacium sp. [1] L3/L4	0.0	-	-	16.7	1.0	0.2	6.3	1.0	0.1
Acanthocephala									
Corynosoma sp. cystacanth	10.0	1.0	0.1	8.3	1.0	0.1	9.4	1.0	0.1
Echinorhynchus sp. immature	0.0	-	-	8.3	1.0	0.1	3.1	1.0	<0.1
Echinorhynchus gadi [1,3]	20.0	3.3	0.65	8.3	1.0	0.1	15.6	2.8	0.4
Echinorhynchus salmonis	45.0	7.6	3.4	16.7	1.5	0.3	34.4	6.5	2.2
Neoechinorhynchus sp. cystacanth	0.0	-	-	25.0	1.3	0.3	9.4	1.3	0.1
Neoechinorhynchus (Neoechinorhynchus) tumidus [1]	15.0	2.3	0.35	16.7	2.5	0.4	15.6	2.4	0.4
Copepoda									
Salmincola extensus	15.0	1.3	0.2	25.0	4.0	1.0	18.8	2.7	0.5
Unidentified Cysts	5.0	2.0	0.1	8.3	2.0	0.2	6.3	2.0	0.1

Parasite Taxon	2021 (n = 20)			2022 (n = 12)			Years Combined (n = 32)		
	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
TOTAL	**100.0**	**172.1**	**172.1**	**100.0**	**57.9**	**57.9**	**100.0**	**129.3**	**129.3**

Note: Blue-shaded species are parasites of freshwater origin. Green-shaded can be freshwater, brackish, or marine.

1 – Parasite taxa not previously reported from Arctic cisco.

2 – Recently reclassified from *Lecithaster gibbosus* (Vainutis and Voronova 2025) and recent genetic evidence (Krupenko et al. 2022) suggests this species and *L. confusus*, the other in this genus previously reported from Canadian waters (Gibson 1996), are the same species.

3 – *E. gadi* has many synonymized names and previous reports of other *Echinorhynchus* species in Arctic cisco may have actually been *E., gadi.*

Table 5. Summary information for parasites collected from female and male Arctic cisco sampled at Shingle Point, Yukon in 2021 and 2022.

Parasite Taxon	Site(s) of Infection	Potential Dietary Source	Females (n = 15)			Males (n = 17)		
			Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
Myxozoa								
Henneguya sp. [1]	Subdermal	None - direct infection	0.0	-	-	5.9	15	0.9
Trematoda								
Brachyphallus crenatus	Stomach, Intestine	Calanoid Copepods	100.0	208.9	208.9	94.1	31.2	29.4
Derogenes varicus [1]	Stomach	Calanoid Copepods	6.7	1.0	0.1	0.0	-	-
Alloopistolecithum gibbosum [1]	Intestine, Stomach	Calanoid Copepods	13.3	3.5	0.5	17.6	9.3	1.6
Monogenea								
Discocotyle sagittata [1]	Gills	-	0.0	-	-	11.8	1.5	0.2
Cestoda								
Bothrimonus sturionis	Intestine	*Onisimus litoralis*, Gammarid Amphipods	60.0	26.0	15.6	11.8	10.0	1.2
Dibothriocephalus sp. plerocercoids	Stomach, Intestine, Body Cavity	Copepods	53.3	1.5	0.8	41.2	3.4	1.4
Proteocephalus sp. immature	Intestine	Copepods	6.7	1.0	0.1	5.9	4.0	0.2

Parasite Taxon	Site(s) of Infection	Potential Dietary Source	Females (n = 15)			Males (n = 17)		
			Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
Triaenophorus crassus plerocercoids [1]	Muscle	Copepods (usually Cyclopoid)	20.0	8.7	1.7	11.8	1.0	0.1
Nematoda								
Nematoda unidentified	Body Cavity, Stomach	Unknown	0.0	-	-	11.8	1.0	0.1
Anisakis simplex complex L3	Muscle	Euphausiids	6.7	1.0	0.1	0.0	-	-
Hysterothylacium sp. [1] L3/L4	Intestine	Gammarid amphipods	0.0	-	-	11.8	1.0	0.1
Acanthocephala								
Corynosoma sp. cystacanth	Intestine	*Monoporeia affinis*; other benthic Peracaridans	20.0	1.0	0.2	0.0	-	-
Echinorhynchus sp. immature	Intestine	Amphipods	0.0	-	-	5.9	1.0	0.1
Echinorhynchus gadi [1]	Intestine, Stomach	Caprellid amphipods; *Gammarus* spp.	26.7	3.3	0.9	5.9	1.0	0.1
Echinorhynchus salmonis	Intestine, Body Cavity	Benthic amphipods	40.0	3.8	1.5	29.4	9.6	2.8

Parasite Taxon	Site(s) of Infection	Potential Dietary Source	Females (n = 15)			Males (n = 17)		
			Prevalence (%)	Mean Intensity	Mean Abundance	Prevalence (%)	Mean Intensity	Mean Abundance
Neoechinorhynchus sp. cystacanth	Encysted on hindgut	Ostracods	0.0	-	-	17.6	1.3	0.2
Neoechinorhynchus tumidus [1]	Intestine	Ostracods	26.7	2.0	0.5	5.9	4.0	0.2
Copepoda								
Salmincola extensus	Fins	-	20.0	1.3	0.3	17.6	4.0	0.7
Unidentified Cysts	Muscle	-	6.7	2.0	0.1	5.9	2.0	0.1
TOTAL			**100.0**	**231.3**	**231.3**	**100.0**	**39.5**	**39.5**

Note: Blue-shaded species are parasites of freshwater origin. Green-shaded can be freshwater, brackish, or marine.

1 – Parasite taxa not previously reported from Arctic cisco.

Table 6. Comparison of prevalence, mean intensity and mean abundance between years (2021 vs 2022) and host sex (female vs male) using a Kolmogorov-Smirnov test. Significant differences (p value ≤0.05) are presented in bold. NS = not significant.

Parasite Taxon	Prevalence (%)		Mean Intensity		Mean Abundance	
	2021 vs 2022	Female vs Male	2021 vs 2022	Female vs Male	2021 vs 2022	Female vs Male
Brachyphallus crenatus	NS	NS	NS	**0.023**	NS	**0.019**
Bothrimonus sturionis	NS	**0.049**	NS	NS	NS	**0.049**
Dibothriocephalus sp. plerocercoids	NS	NS	NS	NS	NS	NS
Echinorhynchus salmonis	NS	NS	NS	NS	NS	NS
Salmincola extensus	NS	NS	NS	NS	NS	NS
All Parasites [1]	NS	NS	NS	**0.016**	NS	**0.016**

1 – Includes taxa not analysed individually.

FISH HEALTH

Due to the small sample size for many of the parasite species, most parasites were combined into major taxonomic groups (Trematoda, Cestoda, and Acanthocephala) for statistical analyses. Remaining parasites had insufficient sample size for more detailed comparisons. Plots and linear regressions of parasite load versus condition factor and HSI and GSI showed no significant or consistent trends for any of the three major parasite taxa or for all parasites combined (Figures 7-9). Given the relatively low overall parasite loads for most of the male Arctic cisco and potential confounding differences in mean size and HSI between sexes, it was determined that comparing high and low parasite loads with HSI would only be performed for female Arctic cisco with years combined. Mean HSI for the low and high parasite load groups were 1.51 (n = 6) and 1.58 (n = 9), respectively. The t-Test indicated a significant difference ($p < 0.05$) between the two groups (Table 7). However, small sample sizes limit interpretation of these results. There is no conclusive evidence that parasites negatively affected the health of Arctic cisco sampled from Shingle Point in 2021 and 2022.

Table 7. Summary statistics for t-Test comparing low versus high total parasite infection loads in female anadromous Arctic cisco from Shingle Point, Yukon.

	HSI	**High v Low Identifier**
Mean	1.55	0.6
Variance	0.10	0.26
Observations	15	15
Hypothesized Mean Difference	0	
df	24	
t Stat	6.15	
P(T<=t) one-tail	1.18267E-06	
t Critical one-tail	1.71	
P(T<=t) two-tail	2.36534E-06	
t Critical two-tail	2.06	

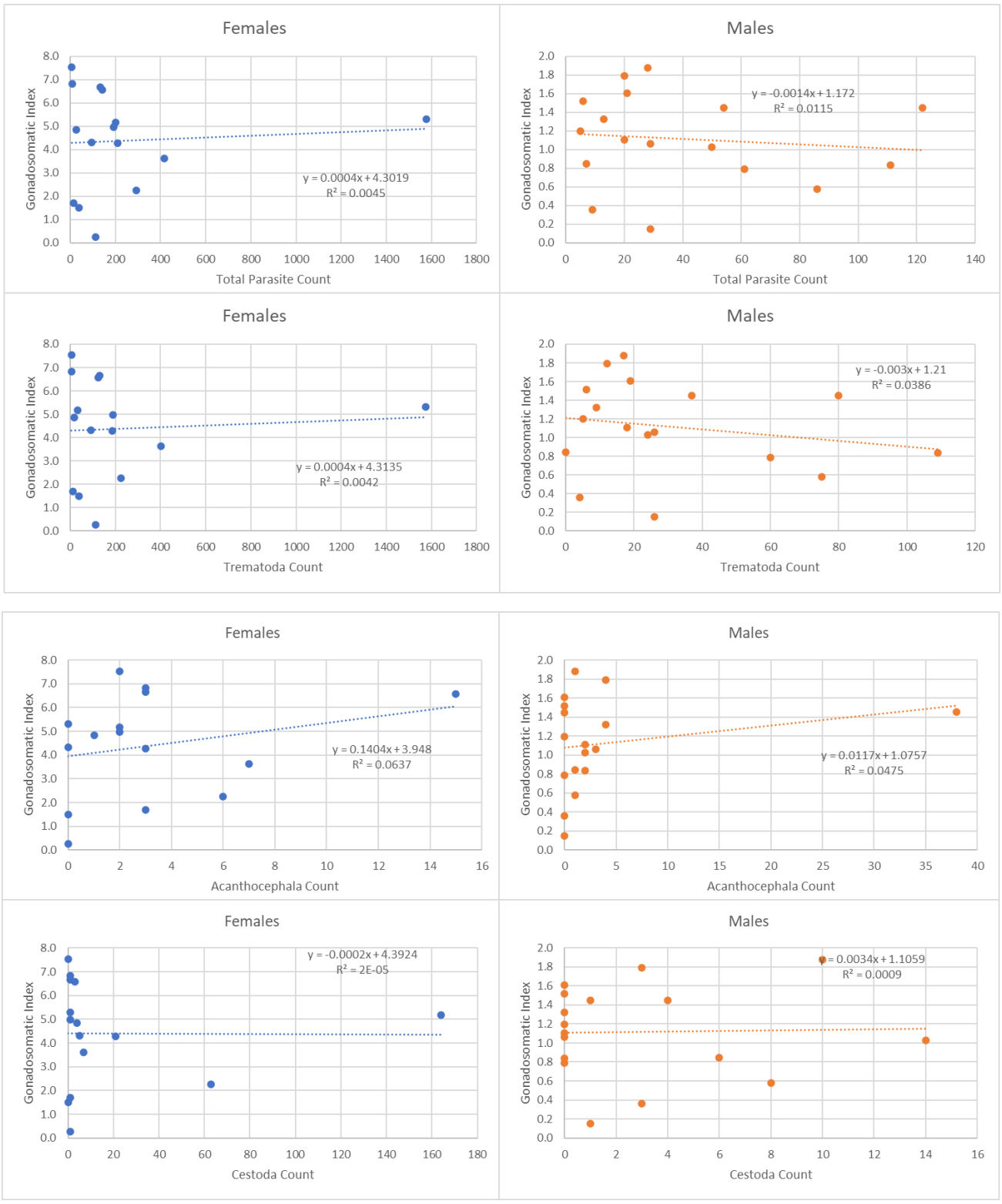


Figure 7. Scatterplots, by total parasite and major taxonomic groupings, of parasite abundances versus gonadosomatic indices of female and male anadromous Arctic cisco from Shingle Point, Yukon.

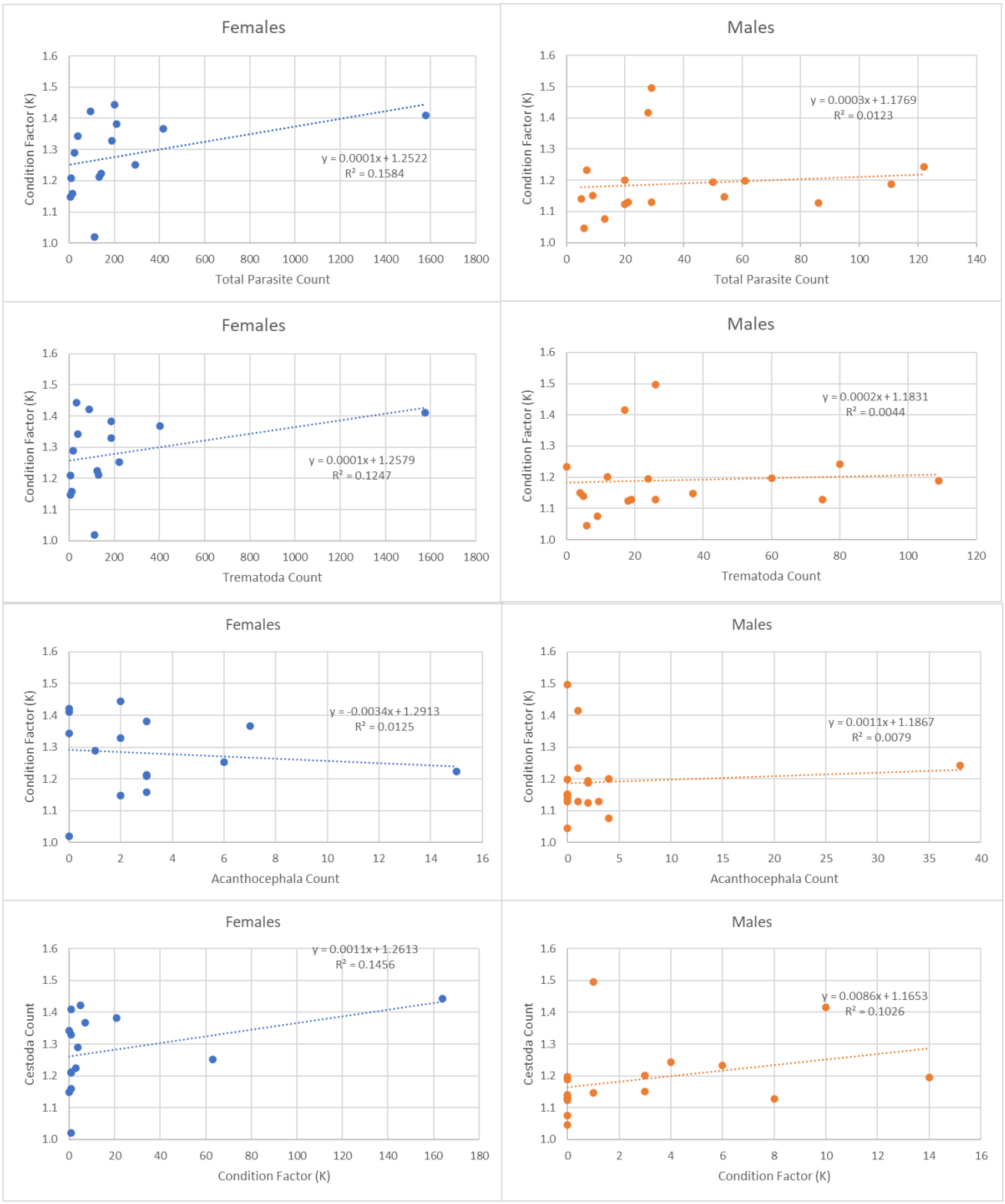


Figure 8. Scatterplots, by total parasite and major taxonomic groupings, of parasite abundances versus condition factor of female and male anadromous Arctic cisco from Shingle Point, Yukon.

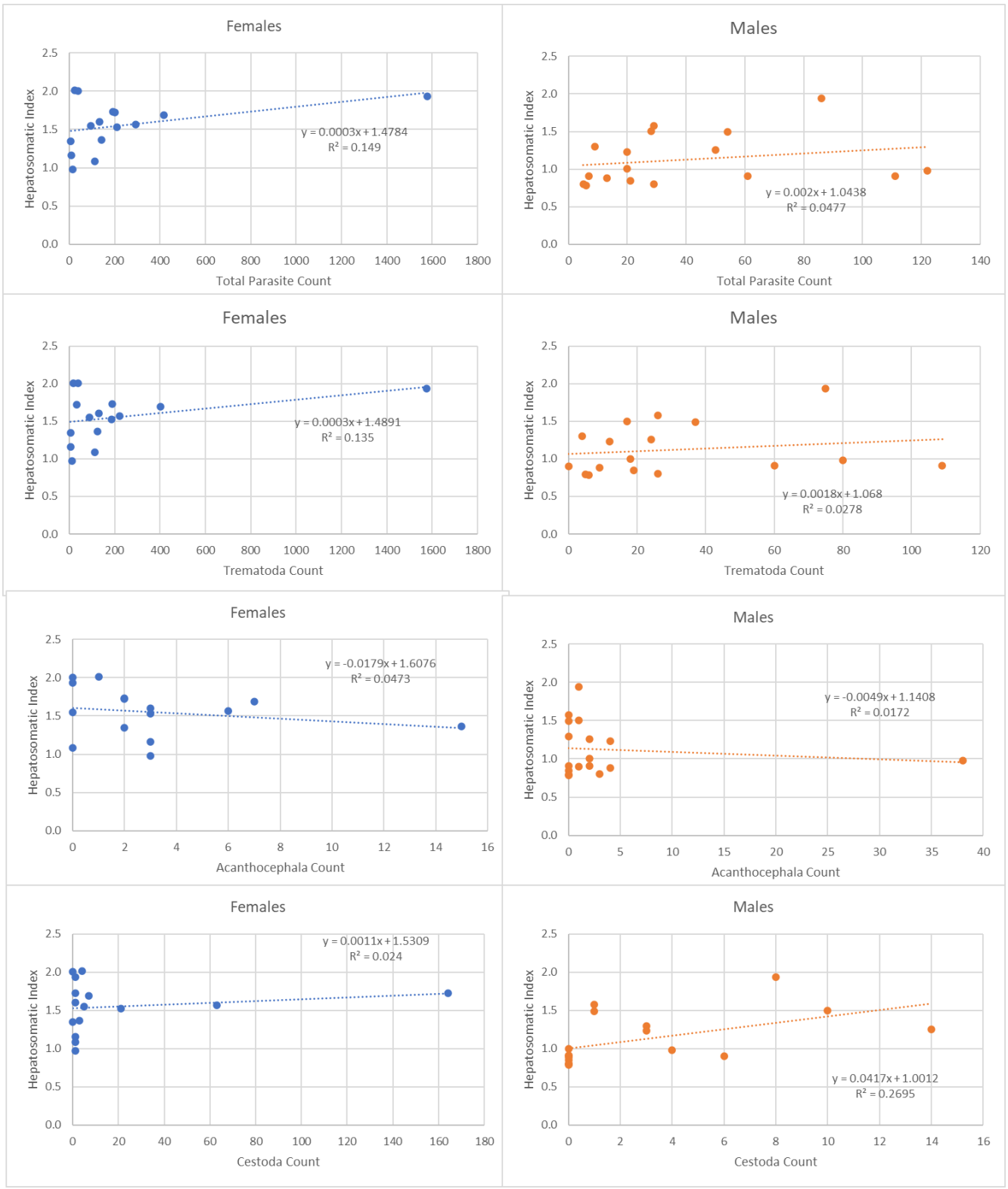


Figure 9. Scatterplots, by total parasite and major taxonomic groupings, of parasite abundances versus hepatosomatic indices of female and male anadromous Arctic cisco from Shingle Point, Yukon.

DISCUSSION

DIET

Arctic cisco are one of the most common anadromous fish species that inhabit the band of warm, brackish water found along the Beaufort Sea coasts of Alaska and Canada (Craig et al. 1985; Jarvela and Thorsteinson 1999). While fish as young as age-0 are known to move offshore into higher salinity waters, densities in that habitat are typically very low (Craig et al. 1985; Underwood et al. 1992; Jarvela and Thorsteinson 1999). The diet of Arctic cisco sampled from Shingle Point is generally consistent with a nearshore brackish habitat. For example, *Eurytemora, Acartia,* and *Limnocalanus* have been previously identified from nearshore areas of the Mackenzie River plume in the Beaufort Sea, with *Limnocalanus* one of the most abundant taxa (Walkusz et al. 2010). These three copepod taxa were among the most frequently observed in sampled Arctic cisco stomachs, though they comprised relatively small proportions of the total prey abundance and weight. While *Calanus* copepods comprised a large proportion of the total prey abundance in both survey years, and while they can be found at low densities in nearshore areas, the taxon is usually more abundant in offshore waters of the Beaufort Sea (Walkusz et al. 2010). Most *Calanus* (958 of 968) were recovered from three stomachs (1 in 2021 and 2 in 2022). While the remainder of the diet of the 2021 individual was comprised of *Acartia*, *Mysis*, and Chironomidae, which indicated nearshore feeding, the remainder of the diet from the 2022 fish included taxa (e.g., *Sabinea septemcarinata* zoea and *Thysanoessa raschii*) that suggested they may have been recently feeding in more saline waters.

Similar observations were noted from stomachs of young Arctic cisco in the Alaskan Beaufort Sea (von Biela et al. 2013), whose diets shifted to larger taxa (e.g., *Calanus* copepods) with increased body size; however, these individuals generally remained in nearshore habitat. Mysids are also thought to be an important dietary component for several nearshore fish species along the Beaufort Sea coast (Jarvela and Thorsteinson 1999), but they were uncommon in Arctic cisco sampled from both years. Insects found in the stomachs of Arctic cisco were almost exclusively adults of terrestrial taxa and 79 of the 86 identified individuals were all consumed by a single female fish captured in 2021 that also had *Limacina* and *Calanus* in its stomach. A possible explanation may be that these insects were washed into a river during a storm event and transported as a floating mat to the Beaufort Sea where the fish opportunistically preyed on the dead insects.

Although the stomach contents of the Arctic cisco in the current study consisted primarily of pelagic taxa, other research has noted greater dietary diversity for the species, including pelagic and benthic crustaceans and small fishes typically found in coastal marine habitat (Dunton et al. 2006; Von Biela et al. 2013; Coad and Reist 2018). Analyses from a study using fatty acid and stable isotope tracers to quantify ecological niches for several Beaufort Sea fish species (Brewster et al. 2016), categorized Arctic cisco as a coastal fish with a broad niche region that feeds on both pelagic and benthic prey taxa. Arctic cisco also appear to feed at relatively high trophic levels for a coregonine (Brewster et al. 2016; Coad and Reist 2018). Of the six coregonines analysed by Brewster et al. (2016), only Inconnu, which is mainly a piscivore, had a higher δ15N signature. The parasite infracommunity of Shingle Point Arctic cisco also suggests a more diverse diet with greater input of benthic invertebrates than the stomach contents indicate (see discussion below).

PARASITES

The 16 parasite species identified from our study of Shingle Point Arctic represent a more diverse infracommunity than has been reported previously for the species (McDonald and Margolis 1995; Stewart and Bernier 1999; Polyaeva 2021). This is the first time that eight of these taxa have been identified from Arctic cisco (Table 4), although several have been identified from other North American *Coregonus* species and the remainder from other salmonids (salmon and char) (Arai 1989; McDonald and Margolis 1995; Gibson 1996; Arai and Smith 2016).

The parasite community includes a mix of four primarily freshwater, seven primarily marine parasites, and six that could be freshwater, brackish or marine. Of the freshwater taxa, *Dibothriocephalus, Triaenophorus,* and *Neoechinorhynchus* are considered long-lived (months to years) in the larval stages observed (Moravec and Scholz 1994; Stewart and Bernier 1999; Dieterich and Eckmann 2000) and are not necessarily indicative of recent feeding in freshwater environments. The *Proteocephalus* sp. plerocercoids found in two cisco foreguts, suggest the hosts had recently fed in freshwater. Although one had an empty stomach, the other had a chironomid and freshwater cyclopoid copepod in its stomach. *Discocotyle sagittata* and *Salmincola extensus* both infect Arctic cisco by direct transmission and not via an intermediate host and may not be tolerant of the brackish or marine habitats that they may be exposed to via an anadromous host. In a study of four Irish lakes (three freshwater and one brackish), Byrne et al. (2000) found that *D. sagittata* was absent only from the brackish lake. A single *Salmincola edwardsii* was found on an anadromous Southern Asian Dolly Varden (*Salvelinus curilus*) in

Japan, but intensity and prevalence of the parasite were higher in freshwater samples (Hasegawa et al. 2022). The apparently low tolerance of these two genera for higher salinity suggests that the infected fish in our study may have been relatively recent migrants to the Beaufort Sea. Of the fish infected with either of these species in 2021 and 2022, all but one had either empty stomachs or had recently consumed small numbers of freshwater and/or brackish invertebrates. The remaining individual had stomach contents suggestive of feeding in a more saline environment, but a parasite fauna with almost no species of marine origin, indicating that it too had only recently entered such habitat.

Two of the marine species, the cestode *Bothrimonus sturionis* and trematode *Brachyphallus crenatus* are common marine parasites that can be found in anadromous salmonids captured in freshwater but only shortly after they have returned from the sea (Stewart and Bernier 1999; Unger et al. 2014). In this study, the high prevalence, mean intensity, and mean abundance of *B. crenatus* support the results of the dietary analyses, which suggested that most of the captured Arctic cisco had been feeding primarily in brackish and/or marine waters on large numbers of copepods. In addition, the presence of *B. sturionis*, and *E. salmonis* indicates these fish had been recently feeding on greater proportions of benthic or ice-associated amphipods. Several studies have identified infection rates of <1% for *E. gadi* and *E. salmonis* in their intermediate amphipod hosts (Amin 1978; Marcogliese 1994; Benesh et al. 2015), suggesting large numbers would need to be consumed to reach even moderate prevalence and mean intensity levels in the fish host.

Of particular interest to harvesters are the cysts of the cestode *Triaenophorus,* that infects the muscle of the fish host and can affect the quality of fish harvested for subsistence and health of the fish host. Both prevalence and intensity of *Triaenophorus* in their intermediate fish hosts can vary by fish community composition, season, invertebrate host distribution, and feeding strategy, as well as age and size structure of the fish population (Valtonen et al. 1989; Schähle et al. 2016). For example, a sympatric pair of European Whitefish, *C. lavaretus,* subspecies in Teletskoye Lake in Siberia show that different feeding strategies had different infection levels of *Triaenophorus*, with higher prevalence and mean intensity in the more planktivorous form (Kashinskaya et al. 2021). Subpopulations of Arctic cisco within the same lake may experience different exposure rates to this parasite either via distribution patterns of the copepod second intermediate host or the snail first intermediate host. If the timing of *Triaenophorus* egg released from Northern Pike coincides with Arctic cisco habitat use in particular freshwater habitats but

not others, there could be large observed differences in infection intensities among groups or subpopulations of Arctic cisco. A larger sample size of Arctic cisco that includes samples from different locations and/or times of year would be necessary to conduct a full assessment of the scope of *Triaenophorus* infections in Arctic cisco in the region.

FISH HEALTH

Depending on the species (both host and parasite), parasitic infections can impact fish health in a variety of ways. For example, the proboscis of many acanthocephalans will penetrate the intestine and cause inflammation of the tissue, a thickening of the gut wall, and accumulation of host immune response cells (Dezfuli et al. 2008). Interestingly, there is evidence that acanthocephalans act as toxic sinks and bioaccumulate organic pollutants, protecting their hosts from some of the negative health effects of living in polluted environments (Sures and Siddall 1999; Filipović et al. 2013; Molbert et al. 2020). Thus, in some instances acanthocephalans may be more beneficial than detrimental to their fish hosts as organic pollutants accumulate in aquatic environments. The effects on host tissues can be highly variable. The load of the parasitic isopod *Ceratothoa italica* was negatively correlated with HSI in a population of Mediterranean Striped Sea Bream (*Lithognathus mormyrus* Linnaeus 1758) that was heavily fished and under additional stresses (Sala-Bozano et al. 2012). Infected fish were also significantly smaller than uninfected onesones. In contrast, Nnabuchi et al. (2015) noted a positive correlation between between HSI andand parasite intensity in two host catfish (*Clarias* spp.) in Nigeria. This increase in HSI was accompanied by increases in liver enzyme activity, decreases in hemoglobin concentration and red blood cells, and an increase in white blood cells. Parasites can also affect host responses to an infection. For example, *Dibothriocephalus dendriticus* plerocercoids in Arctic cisco have been shown to produce prostaglandins that potentially alter the antiparasitic immune response of the host, thus improving parasite survival (Kutyrev et al. 2017). The factors chosen to study were commonly used metrics of health for fish.

Although there was a significant difference in mean HSI between female Arctic cisco with low and high parasite loads, linear regressions showed no significant correlations or trends between parasite infection intensities and Arctic cisco health in our study. Small sample sizes may be a contributing factor. For example, there remains potential for some parasite species to affect these hosts at higher intensities than were observed in our study. Among the parasites identified from Shingle Point Arctic cisco, *Triaenophorus* cysts have most frequently been associated with

negative effects to fish health. Generally, the prevalence and number of *Triaenophorus* cysts in Arctic cisco populations will increase with age and size of the fish (Boily 1993). *Triaenophorus* infections in *Coregonus lavaretus* in Finland were noted to negatively affect growth rates in older fish with the highest parasite loads (mean abundances >3 cysts per fish) (Pulkkinen 1999). Mean abundance of *Triaenophorus* cysts in our study (0.1 per fish) were substantially lower than the values reported by Pulkkinen (1999). Similarly, Haldorson (1984) noted that none of the parasites in Arctic cisco from the Alaskan Beaufort Sea appeared numerous enough to negatively affect host health. West (1986) identified no effects to the Arctic cisco infected with low densities of cestodes and trematodes in coastal lagoons of the Alaskan Beaufort coast.

Another parasite of interest in relation to Arctic cisco health is the freshwater myxosporean, *Henneguya* sp. *Henneguya* species that infect fish gills at often high intensities, can cause suffocation and mortality (Bowser and Conroy 1965; Whitaker et al. 2005). However, *Henneguya* species that infect muscle tissue, such as the ones from these cisco, have not been linked to negative impacts to fish health in salmonids, although studies focusing on these muscle-infecting species are limited. The whitish *Henneguya* cysts in muscle tissue can also reduce the quality and marketability of fish by causing a milky appearance when the cysts are burst (Boyce et al. 1985; Wagner 2016). However, the *Henneguya* cysts in Arctic cisco were exclusively subdermal thus minimizing potential effects to the fishes submitted through this study. The parasite was also found in only a single Arctic cisco captured in 2022, which is insufficient to assess potential effects to the health of the host or the fishery. Should *Henneguya* increase in prevalence, abundance or intensity in Shingle Point Arctic cisco, there could be greater impact to quality fish for subsistence harvests.

Potential linkages between fish health and the two most prevalent and abundant parasite species in the sampled Arctic cisco, *B. sturionis* and *B. crenatus,* have not been previously studied. The small sample size of Arctic cisco in our study and the low intensities of most parasite species, particularly those previously reported to have effects on fish health, prevent a more detailed analysis. Additional surveys from this area with larger sample sizes across seasons and from multiple locations are necessary to support a robust statistical analysis of the potential effects of parasites on these fish. Fish naturally acquire parasites and there is a baseline parasite abundance that is expected and manageable without adversely affecting the population. This baseline varies by fish host and parasite taxa; however, there are additional stressors that can alter the level,

variety, and pathogenicity of parasites that fish can manage, such as contaminants, warmer waters, and dietary shifts (Karvonen et al. 2010; Marcogliese and Pietrock 2011; Lõhmus and Björklund 2015; Byers 2021; Sures and Nachev 2022).

For example, high temperatures have been correlated with enhanced parasite transmission and persistence (Franke et al. 2017) and increased growth rates within fish hosts (Macnab and Barber 2011). In addition to increased parasite growth rates, Macnab and Barber (2011) also observed that Threespine Stickleback infected with the cestode *Schistocephalus solidus*, showed significant preference for warmer water, further enhancing parasite growth and production. Shifts in the diet of salmonids in Norwegian lakes from pelagic to more benthos led to decreases in zooplankton-borne parasite taxa (Amundsen et al. 2019). Such a dietary shift in Arctic cisco during freshwater and/or marine periods of residency could reduce the prevalence and intensity of several of the cestodes (e.g., *Dibothriocephalus* and *Triaenophorus*) while increasing infection rates of acanthocephalans and possibly introducing novel parasite taxa. Parasites are also known to interact with anthropogenic stressors (such as contaminants) to decrease host health and increase mortality by reducing resistances and/or tolerances to infections (Marcogliese and Pietrock 2011). These shifts in parasite prevalence and intensity can affect both fish and human health. Monitoring parasite loads in larger sample sizes on an annual basis could provide a better indication of fish health as it relates to parasite infection.

FUTURE DIRECTIONS

Concerns raised by Inuvialuit harvesters at Shingle Point and the Aklavik HTC initiated this study. Though parasite identification and intensities, and subsequent effect on fish condition were the primary goals of this analysis, there are still community driven questions left unanswered. For example, how do increases in water temperature and changes in salinity contribute to parasite intensities observed in Arctic cisco, at what point will body condition be negatively affected, and what are the potential impacts to humans (i.e. need for development of thresholds)? Two of the parasites found in these cisco, *Anisakis* and *Dibothriocephalus* are zoonotic, meaning that they can affect human health if infected fish are consumed (Dick et al 2001, Government of British Columbia, 2013, Waeschenbach et al 2017). Two additional taxa (*T. crassus* and *Henneguya* sp.) could potentially affect the quality of harvested fish. These species could be prioritized to monitor over time to address community questions around fish health and meat quality for consumption. In this study Arctic cisco were not cut prior to analysis. Although there was

concern from harvesters that the samples submitted would not include the fish with high parasite abundance and intensity, this was done to ensure an unbiased sample of parasite abundance on individuals collected. With the conclusion of this study, the Aklavik HTC has indicated the need to repeat this study periodically for monitoring purposes, and allow for harvesters who identify fish with large amounts of parasites be submitted for analysis on condition and parasite intensity. Though, as seen in the present study, sample size is a limiting factor to provide adequate analysis of all parasites present. Even if periodically monitored, a study that incorporates large sample sizes of whole fish and precut fishes (with high intensity parasites observed by harvesters) would be challenging due to the time, cost, and hesitancy from harvesters to submit whole fish. Though established programs such as ACES can contribute samples, there are limitations which include fish at specific life history stages (adult non-spawning) and sample sizes (annual maximum n=20). However, if there is a desire to monitor parasite abundance and impacts on Arctic cisco over time, then standardized methodology geared toward parasite identification at a species level, abundance, and parasite host condition, in addition to oceanographic parameters (e.g. salinity, temperature) would need to be developed to better address specific questions on changes observed.

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