Fisheries monitoring and biological data of the Yellowknife River Cisco *(Coregonus artedi)* population, 1999–2020

Ellen V. Lea, Cameron Stevens, Collin Arens, and Colin P. Gallagher

Fisheries and Oceans Canada
1 Arctic Road, PO Box 1871
Inuvik, NT, X0E 0T0

2023

Canadian Manuscript Report of Fisheries and Aquatic Sciences 3268

Fisheries and Oceans Canada Pêches et Océans Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Canadian Manuscript Report
of Fisheries and Aquatic Sciences 3268

2023

FISHERIES MONITORING AND BIOLOGICAL DATA OF THE YELLOWKNIFE RIVER CISCO *(COREGONUS ARTEDI)* POPULATION, 1999–2020

by

Ellen V. Lea[1], Cameron Stevens[2], Collin Arens[2], and Colin P. Gallagher[3]

[1]Fisheries and Oceans Canada
8 Arctic Road, PO Box 1871
Inuvik, NT X0E 0T0

[2]Golder Associates Ltd.
16820 107 Ave.
Edmonton, Alberta, Canada T5P 4C3

[3]Fisheries and Oceans Canada
501 University Crescent
Winnipeg, MB R3T 2N6

Cat. No. Fs97-4/3268E-PDF ISBN 978-0-660-67545-9 ISSN 1488-5387

Correct citation for this publication:

Lea, E.V., Stevens, C., Arens, C., and Gallagher, C.P. 2023. Fisheries monitoring and biological data of the Yellowknife River Cisco *(Coregonus artedi)* population, 1999–2020. Can. Manuscr. Rep. Fish. Aquat. Sci. 3268: viii + 65 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Lea, E.V., Stevens, C., Arens, C., and Gallagher, C.P. 2023. Fisheries monitoring and biological data of the Yellowknife River Cisco (*Coregonus artedi*) population, 1999–2020. Can. Manuscr. Rep. Fish. Aquat. Sci. 3268: viii + 65 p.

Cisco (*Coregonus artedi*) from the Yellowknife River, Northwest Territories, are an important fishery resource for nearby communities. Biological, catch-effort, and environmental data were collected from the Yellowknife River (Tartan Rapids and Bluefish areas) during their fall spawning run from Great Slave Lake. Data from the commercial harvest (fishery-dependent; 1998–2020) and supplementary monitoring (fishery-independent; 2013–2020) of these adfluvial Cisco were compiled to summarize commercial fishery quotas and reported harvest, characterize population demographics and catch-effort over time, and assess potential associations between relative abundance and seasonal river characteristics. A single commercial fishing licence for Cisco was issued on an annual basis each fall for 1,000 kg from 1998–2002, 2,000 kg from 2004–2005, 1,000 kg from 2010–2018, and 1,500 kg from 2019–2020. Cisco ranged from 102–239 mm fork length, 10.0–139.6 g round weight, and 1 and 9 years of age, with the majority of fish (>99%) being sexually mature. The demographics (length, weight, age) of the spawning population collected from the commercial fishery remained relatively stable between 1999 and 2020. Catch-effort of the commercial fishery varied widely among years without trend, although this was not standardized to the number of individuals/nets used to capture the fish. The biological, catch-effort, and environmental data collected from the Yellowknife River spawning population of Cisco serve as a benchmark for their ongoing assessment and management.

RÉSUMÉ

Lea, E.V., Stevens, C., Arens, C., and Gallagher, C.P. 2023. Fisheries monitoring and biological data of the Yellowknife River Cisco (*Coregonus artedi*) population, 1999–2020. Can. Manuscr. Rep. Fish. Aquat. Sci. 3268: viii + 65 p.

Le cisco de lac (*Coregonus artedi*) de la rivière Yellowknife (Territoires du Nord-Ouest) est une ressource halieutique importante pour les communautés avoisinantes. Durant sa migration à partir du Grand lac des Esclaves, des données biologiques et environnementales ainsi que des données sur les captures par unité d'effort ont été recueillies dans la rivière Yellowknife (zones des rapides Tartan et de Bluefish). Des données provenant de la pêche commerciale (dépendante de la pêche, 1998-2020) et de la surveillance supplémentaire (indépendante de la pêche, 2013-2020) de ces ciscos de lac adfluviaux ont été compilées. L'objectif de cette compilation est de résumer les quotas de la pêche commerciale et la pêche déclarée, de caractériser la démographie de la population et les captures par unité d'effort au fil du temps, et d'évaluer les liens potentiels entre l'abondance relative du cisco de lac et les caractéristiques saisonnières de la rivière. Un seul permis de pêche commerciale a été délivré annuellement, à l'automne, pour 1 000 kg de 1998 à 2002, 2 000 kg de 2004 à 2005, 1 000 kg de 2010 à 2018, et 1 500 kg de 2019 à 2020. La longueur à la fourche du cisco de lac variait de 102 à 239 mm, son poids brut, de 10,0 à 139,6 g, et son âge, de 1 à 9 ans. La majorité des poissons (> 99 %) étaient sexuellement matures. Les données démographiques (longueur, poids, âge) de la population reproductrice de ciscos de lac de la rivière Yellowknife recueillies dans le cadre de la pêche commerciale sont restées relativement stables entre 1999 et 2020. Les captures par unité d'effort de la pêche commerciale ont grandement varié au fil des années et ne révèlent aucune tendance; toutefois, les données n'ont pas été normalisées en fonction du nombre d'individus/de filets utilisés pour la pêche. Les données biologiques et environnementales ainsi que les données sur les captures par unité d'effort recueillies auprès de la population reproductrice de ciscos de lac de la rivière Yellowknife servent de point de référence pour leur évaluation et gestion en cours.

1 INTRODUCTION

Three distinct phenotypic morphologies of Cisco (*Coregonus artedi*) (locally called lake herring) are present in the Great Slave Lake (GSL) basin of the Northwest Territories: 1) lacustrine *C. artedi* that are similar to other populations found throughout North America; 2) a Big-eye *C. artedi* morph that remains taxonomically uncertain; and 3) an adfluvial *C. artedi* morph that spawns within the Yellowknife River (Muir et al. 2011, 2014, Blackie et al. 2012, Turgeon et al. 2016). The adfluvial Yellowknife River Cisco population provides an important subsistence, sport, and commercial fishery resource for communities in the area and differs in size, morphology, and life history from the lacustrine form (Muir et al. 2011; Blackie et al. 2012; Vescei et. al 2012; Muir et. al 2014; Mackenzie et al. 2021). Adfluvial Cisco gather in large aggregations in the Yellowknife River to spawn during fall (October to November), when water temperatures drop to approximately 3–5°C, to spawn over gravel or stony substrates (Scott and Crossman 1973). Known spawning locations of adfluvial Cisco in the Yellowknife River include Tartan Rapids, below Prosperous Lake, Bluefish Rapids, above Prosperous Lake, and potentially the Cameron River Narrows, above the confluence with Prosperous Lake (Vescei et. al 2012; Dominion Diamond 2014; Golder 2018; 2019; Mackenzie et al. 2021).

Historically this population was fished regularly by the Yellowknives Dene First Nation, although they have reported that by the 1950s the fish populations in the Yellowknife River and Yellowknife Bay had been negatively affected by mining operations in the area and commercial fishing on Great Slave Lake (Degray 2020). In recent years, Yellowknife River Cisco have been targeted by sport fishers at Tartan Rapids each fall during their annual spawning migration. Cisco can be captured by dip net under the authority of a sport fishing licence issued under the *Northwest Territories Fishery Regulations*.

A small-scale commercial fishery targeting Yellowknife River Cisco, licenced as a Stage I License under Fisheries and Oceans Canada's (DFO) New Emerging Fisheries Policy (DFO 2008) (henceforth referred to as a 'commercial fishery'), began at Tartan Rapids (a section of the Yellowknife River; Figure 1) in 1998. A single licence was issued to a local resident to harvest Cisco using a dip net, which were primarily sold for bait used by recreational anglers during winter. In response to concerns about the status of the population, this fishery was put on hold 2006–2009 to allow for a population assessment using available data. While this assessment concluded that the commercial harvest could continue sustainably at existing levels (DFO unpublished), DFO committed to an enhanced monitoring program to collect additional information on the population and its habitat. While concerns continue to be raised regarding the status of the Yellowknife River Cisco population, DFO has also received requests to expand the commercial harvest through additional licences in recent years.

Biological, relative abundance, and environmental data have been collected from the Yellowknife River Cisco population that can be used to inform fisheries management decision-making. Under the conditions of a commercial licence issued under the New Emerging Fisheries Policy, licence holders are required to record catch and biological information to support the assessment of the feasibility and sustainability of the fishery over time, and potential advancement in the stages of a developing fishery (DFO 2008). In addition to the information collected from the commercial harvest (fishery-dependent), a fishery-independent sampling and snorkel survey program was conducted with the objective of collecting additional biological, observational, and environmental data during the fall spawning run.

The objective of this report is to compile available data from fishery-dependent and fishery-independent sampling of adfluvial Yellowknife River Cisco during fall, 1998-2020, specifically by:

- Summarizing commercial fishery quotas and reported harvest;
- Characterizing population demographics and examining for trends over time;
- Summarizing metrics of relative abundance (i.e., catch-per-unit-effort data and snorkel survey observations) and examining for trends over time; and
- Determining if there were any associations between relative abundance of Cisco and river discharge and temperature.

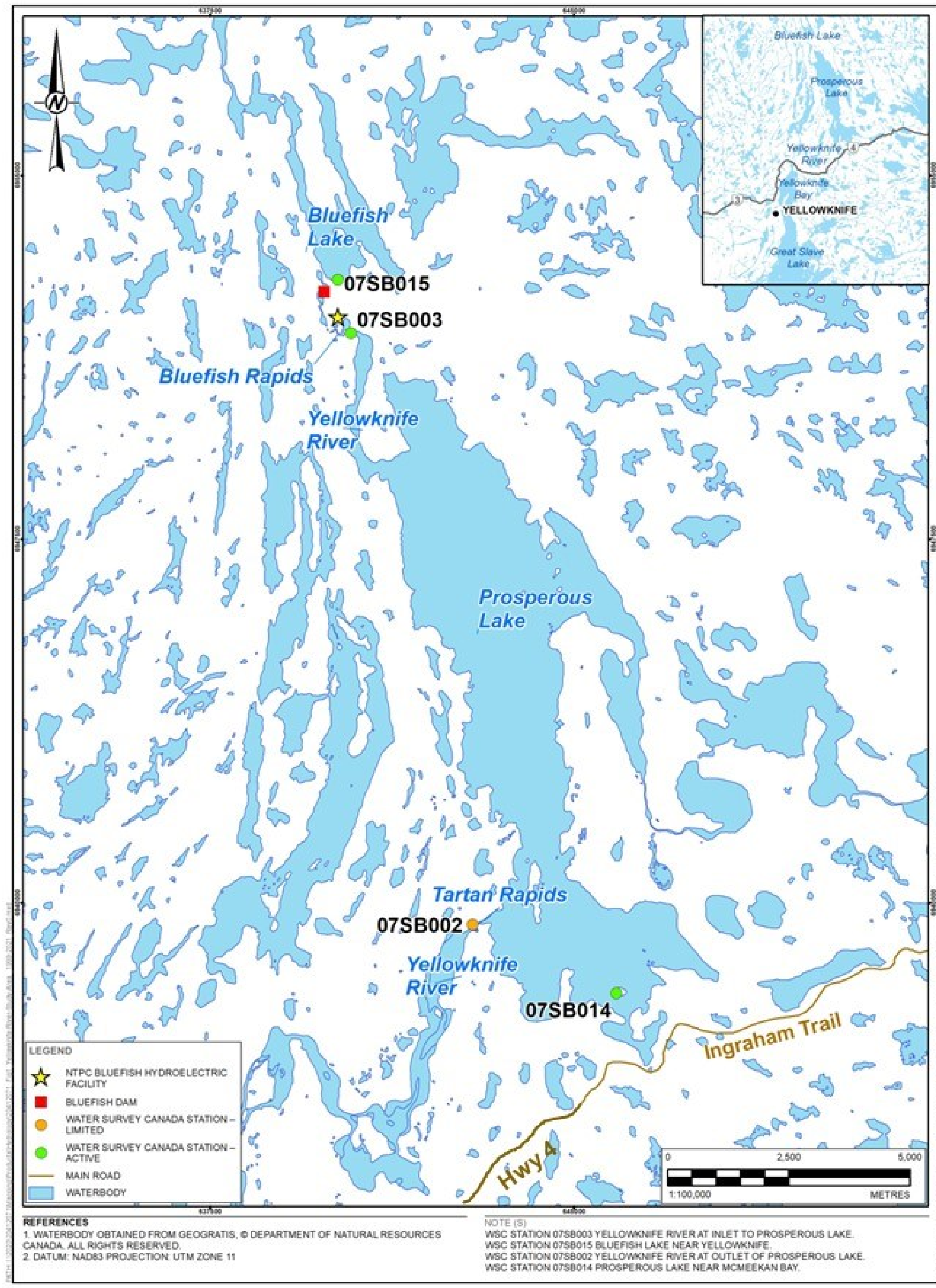


Figure 1. Yellowknife River, Northwest Territories, study area, 1999–2020.

1.1 STUDY AREA

The Yellowknife River drainage basin is in the subarctic Canadian Shield (Taiga Shield Ecozone) north of Yellowknife, Northwest Territories (NWT). The lowest monthly average temperature 1981–2010 was -25.6°C in January and the highest was 17.0°C in July based on Environment and Climate Change Canada's (ECCC) climate normals. Mean annual precipitation is approximately 289 mm, with the majority of precipitation (61% of the annual total) falling June through October. The basin is usually ice covered from October to May and spring freshet peak flows in the North Slave region typically occur in late-June.

The Yellowknife River flows south into Yellowknife Bay in Great Slave Lake near the city of Yellowknife. The drainage area of the Yellowknife River at the inlet to Prosperous Lake is estimated to be approximately 11,300 km^2 and approximately 16,300 km^2 at the outlet of Prosperous Lake near Tartan Rapids (ECCC 2021a). The Bluefish Hydroelectric Facility (Bluefish) is approximately 24 km upstream of Great Slave Lake (Figure 1).

Bluefish Lake receives regulated flows from the Duncan Lake control dam at the outlet of Duncan Lake, as part of the Northwest Territories Power Corporation (NTPC) Bluefish Hydroelectric Facility. The Bluefish dam was built at the natural rapids outflow of Bluefish Lake in the Yellowknife River in 1942. Below the dam, the Yellowknife River flows through 780 m intake tunnel-penstocks, discharging through two generating stations and tailrace area immediately above the confluence with the Bluefish Rapids reach of the Yellowknife River. The reach of Bluefish Rapids below the dam functions as a natural spillway for flows not used by the facility. Within the Bluefish Rapids reach, minimum flows for fall-spawning salmonids, including Cisco, are provided through an instream flow gate that was installed in 2012 (Golder 2013).

Potential effects of flow regulation on flow conditions for fall-spawning coregonids such as Cisco and Lake Whitefish (*Coregonus clupeaformis*) may be limited to the Bluefish Rapids reach immediately downstream of the dam, which now functions as a natural spillway during operations. However, ongoing monitoring at the Bluefish Hydroelectric Facility suggest that the maintenance of minimum flow targets, combined with habitat enhancement mitigation are protecting fish spawning habitat conditions at Bluefish Rapids during fall (Golder 2018; 2019).

Discharge at Tartan Rapids is minimally affected by the operation of the hydroelectric facility, based on a comparison of seasonal flow patterns to other rivers in the NWT (Figure A1). For example, seasonal trends in relative flow discharge are very similar between the La Martre River and Yellowknife River, with the exception that peak flows are a few weeks later in the Yellowknife River. Changes of flows and water levels in Prosperous Lake are also influenced by the tributaries that are not affected by the hydroelectric dam; approximately 30% of the cumulative drainage basin area at the outlet of Prosperous Lake are of tributaries not affected by the hydroelectric dam.

1.1.1 Tartan Rapids

Tartan Rapids is located at the outlet of Prosperous Lake as it flows into the Yellowknife River (Figure 1, Figure 2). The survey area at Tartan Rapids includes a section at the outflow of Prosperous Lake upstream of the rapids, a series of three rapids (herein referred to as 'the rapids'), and a section of channel that extends approximately 200 m downstream of the rapids for a total survey length of nearly 500 m (Photo 1).

The upstream survey area is located within the outlet of Prosperous Lake and extends upstream from the first rapid for approximately 75 m of run habitat. The channel is characterized by a mix of boulder, cobble and gravel, and fine sediments collecting in the deepest sections. Bathymetry increases from shallow sloping banks to a mid-channel depth greater than 2 m.

The rapids are separated by a run channel morphology for a length of approximately 160 m and an average width of approximately 30 m. Depth fluctuates seasonally but in the fall the rapids are shallow (0.5–1.0 m water depth) and dominated by boulder with interstitial gravel. The runs between the rapids are deep (1.0 m to > 3.0 m) and consist of large boulders (up to 2 m diameter), bedrock, and a mixture of rock substrates of varying sizes. The right downstream bank is composed of a steep bedrock wall with undercutting, and the left downstream bank has a moderate slope with a mixture of boulder, cobble, gravel, and sand. Negligible amounts of aquatic vegetation are present along the shallow shoreline areas. Adjacent to the left downstream bank at the third rapid, a section of large boulders forms a shallow (0.5–1.0 m depth) pool habitat that is often used as a fish ladder by Cisco migrating around the lower rapids (Photo 2).

The downstream survey area is 240 m long, extending from the third rapid downstream along the Yellowknife River. The outflow of Tartan Rapids is turbulent with back eddies along each shoreline for approximately 90 m downstream of the third rapid (Photo 3). The eddy along the right downstream bank is relatively deep (>2 m) and is adjacent to a steep vegetated and bedrock bank. The eddy along the left downstream bank fluctuates between a snye in low water conditions to a low-flow side channel in high water conditions, and features a small island with a gravel/cobble shoreline. Further downstream the channel becomes uniform with a central thalweg, well-mixed rock substrates of varying sizes, a mean width of 77 m, and a maximum depth of approximately 1.5–2.0 m.

Photo 1. An aerial view of Tartan Rapids, Yellowknife River, Northwest Territories, facing downstream with Prosperous Lake in foreground (October 10, 2016).

Photo 2. A north-west view of a snorkeler (foreground) in a pool adjacent to the third rapid (background) at Tartan Rapids, Yellowknife River, Northwest Territories (October 9, 2013).

Photo 3. An upstream view of a snorkeller in the foreground and the third rapid in the background at Tartan Rapids, Yellowknife River, Northwest Territories (October 26, 2018).

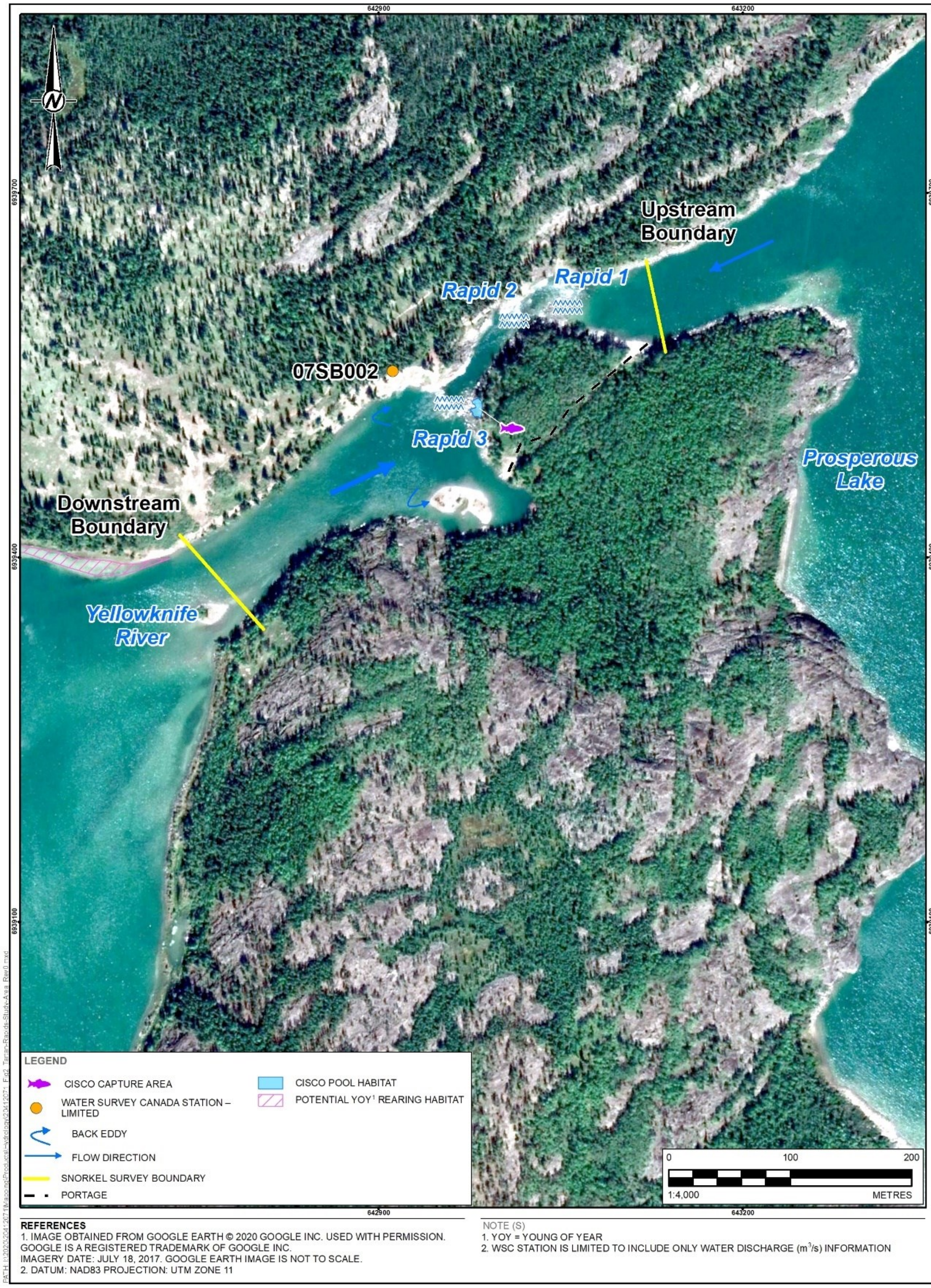


Figure 2. Tartan Rapids, Yellowknife River, Northwest Territories, study area.

1.1.2 Bluefish Rapids and Upper Prosperous Lake (Bluefish)

The Bluefish Rapids are in the lowermost reach of the Yellowknife River below Bluefish Lake and above the confluence with flow received from the tailraces of the NTPC Bluefish Hydroelectric Facility (Figure 1, Figure 3, Photo 4). The survey area of Bluefish Rapids (henceforth referred to as ‘Reach 1’) is 178 m long, shallow (0.2–1.3 m water depth) and dominated by rock substrates of varying sizes (Golder 2016; 2017; 2018; 2019). The waterfalls (approximately 1.5 m tall) in Reach 1 act as a natural barrier to upstream fish movement under most flow conditions and represent the upstream extent of fish sampling in Reach 1 (Photo 5). NTPC maintains a minimum flow of 0.75 m/s at the headgate of the spillway of the Bluefish Hydroelectric Facility, which feeds downstream into the natural channel of Bluefish Rapids.

The Tailrace Area is located southeast of the onshore generators and above the confluence with Bluefish Rapids and the natural channel of the Yellowknife River, before the river enters Prosperous Lake (Figure 3, Photo 4). Both the Tailrace Area and Bluefish Rapids are known spawning locations for adfluvial Cisco and Lake Whitefish in the Yellowknife River; together both locations are referred to as ‘Bluefish’ (Golder 2016; 2017; 2018; 2019). Both generators at the Tailrace Area are operational year-round and provide power to the North Slave electrical grid, which includes the communities of Yellowknife, Behchoko, Dettah and N’Dilo. Relative to downstream sections of the Yellowknife River, the Tailrace Area is characterized by an area of elevated flow velocities that receives flow discharge from the onshore generators. The Tailrace Area spans approximately 100 m wide from shoreline to shoreline, extending approximately 100 m downstream into the natural channel of the Yellowknife River. Bottom substrate in the area consists of predominantly gravel and cobble-size rock with small amounts of hard packed clay patches and sand. The crushed rock was placed along the northern shoreline in the Tailrace Area during generator modifications in 1994. Water depths at the Tailrace Area vary between 0.3 and 2 m during fall.

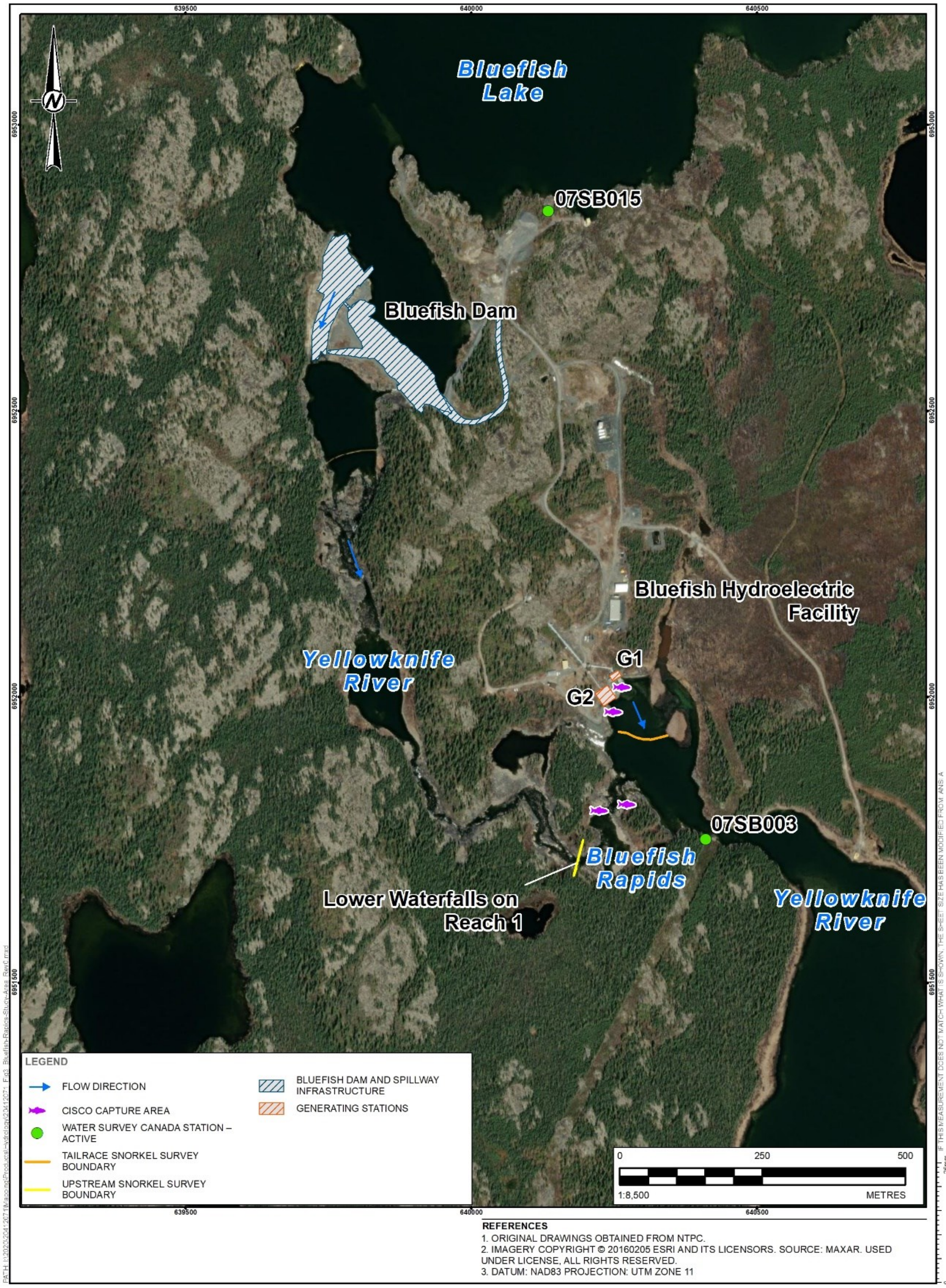


Figure 3. Bluefish Rapids, Yellowknife River, Northwest Territories, study area.

Photo 4. An aerial view of the Bluefish Rapids snorkel area (right) and the inlet to Prosperous Lake (left), Northwest Territories (November 4, 2014).

Photo 5. A southern view of the Reach 1 falls at the Bluefish Rapids, Yellowknife River, Northwest Territories (October 30, 2017).

2 METHODS

All available records of biological, catch-effort, survey observations, and relevant environmental data for Yellowknife River Cisco during the fall spawning run were compiled and summarized (Table 1). Data sources include the commercial dip net fishery at Tartan Rapids (fishery-dependent; 1998–2020) and fishery-independent sampling at Tartan and Bluefish rapids (2013–2020). Fishery-independent methods include the collection of biological and catch-effort data using dip nets (2013–2020) and gill nets (2013–2015, 2018–2020). Additionally, snorkel surveys were used between 2013 and 2020 as an alternative approach to assess relative abundance of Cisco in the Yellowknife River during fall due to potential biases of sampling aggregations of fish with dip nets. Yellowknife River temperature and discharge were summarized as annual cycles and during the study period, defined as October 1–November 7.

2.1 COMMERCIAL FISHERY MONITORING

A local Yellowknife resident fished for spawning adult Cisco using dip nets from Tartan Rapids on the Yellowknife River (Photo 6) under the authority of a commercial fishing licence from 1998–2005 and 2010–2020. Data from the commercial harvest in 1998 and 2003 were not available and therefore not included in this report. Following the conditions of the licence, the fisher reported daily harvest, number of hours fished, and other fish species caught and released. Catch-per-unit-effort (CPUE) was calculated from the commercial fishery (fishery-dependent) as the number of Cisco captured per hour (1999–2005 and 2010–2020). In some years the fisher also recorded the number of bags of fish (9–10 fish/bag) that were packaged in preparation for sale. Additionally, the fisher provided 200 whole frozen Cisco annually to DFO for comprehensive biological sampling.

Photo 6. Local fishers dip netting Cisco at Tartan Rapids, Yellowknife River, Northwest Territories (October 13, 2013).

Table 1. Summary of compiled data for the Yellowknife River, Northwest Territories, Cisco population and environmental conditions, 1999–2020.

Year	Sampling Type				Location		Fish Measurements						Discharge		Temperature		
	Fisheries Independent Sampling	Fisheries Dependent Sampling	Commercial Fishery	Snorkel Survey	Sampling at Bluefish	Sampling at Tartan Rapids	Length	Round Weight	Age	Liver Weight	Gonad Weight	Maturity	Prosperous Inlet	Prosperous Outlet	Prosperous Lake	Bluefish Lake	ECCC
2020	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2019	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2018	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2017	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓
2016	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	*	✓	✓
2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	✓	*	✓	✓
2014	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	✓	*	✓	✓
2013	✓	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓
2012	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓
2011	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓
2010	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	*	✓	✓
2009	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓
2008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓
2007	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	✓	✓
2006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	✓	✓
2005	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	*	*	✓
2004	-	✓	✓	-	-	✓	✓	✓	-	-	-	✓	✓	✓	-	-	✓
2003	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	-	-	✓
2002	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	-	*	✓
2001	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	-	*	✓
2000	-	✓	✓	-	-	✓	✓	✓	✓	-	-	✓	✓	✓	*	*	✓
1999	-	✓	✓	-	-	✓	✓	✓	✓	-	-	-	✓	✓	-	-	✓

*ECCC = Environment and Climate Change Canada, ✓ all data available; * incomplete data; - not collected.*

Note: A commercial harvest occurred in 1998, although no biological or catch-effort records were located. Commercial fishery records from 2003 were unable to be located.

2.2 FISHERY-INDEPENDENT SAMPLING

Fishery-independent sampling of spawning Cisco was conducted annually from Tartan and Bluefish rapids between 2013 and 2020. Generally, fish sample collection and snorkel surveys were performed concurrently and timed to coincide with the fall spawning migration of Cisco, which typically occurs once water temperatures decrease below 5.0°C (Scott and Crossman 1973). Field collections generally began the first week of October and continued into the first week of November, with the general objective to conduct weekly visits (n = 4) during this period. Tartan Rapids was accessed by a small zodiac launched from Cassidy Point on Prosperous Lake, whereas Bluefish Rapids was accessed through travel arrangements by NTPC (either helicopter or boat) as in-kind support for the monitoring program.

All Cisco were collected using small mesh dip nets or with short duration (5–10 min) small-mesh gill net (13 mm stretch mesh, 12.5 m length, 1.8 m depth) sets, depending on the site and conditions. CPUE for dip netting for the fishery-independent sampling was calculated as the number of Cisco captured per net (i.e., fisher) per hour. CPUE for gill nets was calculated as the number of Cisco captured per net, per hour. Consequently direct comparisons in CPUE were not possible between the fishery-dependent and -independent sampling due to the difference in how CPUE were recorded.

Dip nets were typically used when Cisco were abundant at the sampling site, while gill nets were deployed when dip nets failed to catch a large enough sample size. Cisco from Tartan Rapids were primarily captured using dip nets from a pool adjacent to the left downstream bank below the third rapid (Figure 2). Supplemental gill netting within or near the pool was conducted 2013–2015 but was discontinued in subsequent years as dip netting proved to be an effective sampling method and minimized bycatch. Cisco from Bluefish were primarily captured using gill nets in the Tailrace Area in 2013 and 2018–2020 when relatively fewer fish were present. A combination of gill nets and dip nets were deployed in the Tailrace Area and Bluefish Rapids 2014–2017 (Photo 7). Nets were set along the shoreline and within the thalweg of the Tailrace Area in Upper Prosperous Lake, and along both banks of the lower end of Reach 1 (Figure 3). The annual target sample size was approximately 100 Cisco per location, or approximately 25 Cisco captured per survey per site. Captured Cisco were sacrificed and stored frozen until processing. Other fish species and Cisco captured in excess of annual sample size targets were enumerated, measured for length, and released alive.

2.3 FISH PROCESSING

Cisco collected through the commercial fishery and fishery-independent sampling program were thawed and processed within 3–4 weeks following field collection. Fish were photographed (e.g., Photo 8), measured for total and fork length (± 1 mm) and weight (± 1 to 0.001 g), and sagittal otoliths were excised for age estimation. Livers were weighed (± 0.001 g) in 2018 to 2020 and gonads were weighed (± 0.001 g) in 2013 and 2016–2020. Sex and reproductive stage were determined according to criteria outlined in Appendix 2 (e.g., Photos 9,10).

Data sheets and sample labels were verified for completeness and accuracy at the end of each day and were scanned into electronic copies upon completion of the field program. Data were entered into spreadsheets and data screening was performed using scatterplots to visually examine data for data entry errors or unusual data. Extreme outliers were removed from the dataset only if they were determined to be the result of human error (i.e., sampling or measurement error).

Sagittal otoliths were prepared following the “crack and burn” method in order to estimate ages. Otoliths are first bisected in half by applying very slight pressure while sawing the otolith back and forth across the nucleus using a sharp scalpel blade. Both halves are then polished using an electric bench lathe and a felt bob with 30-μm lapping film at low speed. The otoliths are then placed in a foil tray and lightly burned over an ethanol burner, which discolours the otolith and makes the annuli more pronounced. Once cooled, an otolith half is submerged in water under magnification with the polished surface facing upwards and examined under a Leica MZ12.5 dissecting microscope (10-40x) using a reflected light source. To reduce variability and error among ageing technicians, each read of an otolith is assigned a confidence index (CI) describing the quality and clarity of the sample and the confidence of the examiner in their assessment. After ages are obtained and CI is assigned to each sample, an independent age reader re-examines 15–100% of these same samples as part of quality assurance and control (QAQC) processes with the aim to achieve <5% error between readers (see Gallagher et al. 2021).

Photo 7. Setting a small-mesh gill net where Cisco were observed in Upper Prosperous Lake at the Tailrace, Bluefish Hydroelectric Facility, Northwest Territories (October 30, 2018).

Photo 8. A Cisco captured at Bluefish, Northwest Territories, and prepared for processing (December 17, 2019).

Photo 9. A late-stage female Cisco (from processing on December 14, 2018).

Photo 10. A late-stage male Cisco (from processing on November 23, 2020).

2.4 SNORKEL SURVEYS

Snorkel surveys were conducted annually at Bluefish[1] (i.e., Reach 1 and Tailrace Area) and Tartan Rapids 2013–2020 (Table 2) and timed to coincide with the fall spawning migration of Cisco. As the timing of spawning activity for a species is related to water temperature (Scott and Crossman 1973), real-time water temperature data from Water Survey Canada (WSC) stations at Bluefish Lake (07SB015), Yellowknife River above Prosperous Lake (07SB003), were used to plan the Bluefish survey visits (ECCC 2021a). Moreover, water temperature data from WSC stations on the Yellowknife River at the outlet of Prosperous Lake (07SB002) and Prosperous Lake near McMeekan Bay (07SB014) were used to plan visits to Tartan Rapids such that sampling was timed during peak spawning activity (ECCC 2021a).

Snorkel surveys were repeated by the same individual whenever possible to maintain consistency in data collection, with most surveys conducted by the same three fisheries biologists over the study period (i.e., P. Vecsei, F. Larouche, and M. Redmond). During a snorkel survey, one observer was in the water and a nearby data recorder person was on shore (Photo 11). Passive drifting snorkel paths were determined by the observer and recorder on shore prior to each survey. During each survey, the data recorder walked along the shore in constant verbal communication and visual contact with the snorkeler while observations were tallied by species (Photo 12). The number of fish was estimated visually when there were too many to provide an accurate count. There was greater confidence in estimates when fewer fish were present than when larger numbers were present in schools. Snorkel surveys for both Tartan and Bluefish rapids were typically completed during late morning or early afternoon. A complete pass of Tartan Rapids was usually performed in just over 1 hour and a complete pass of the Bluefish snorkel area was typically completed in 1.5 hours.

Table 2. Combined summary of Yellowknife River snorkel surveys for DFO and Northwest Territories Power Corporation, 2013–2020.

<table>
<tr><th rowspan="2">Year</th><th colspan="3">Tartan Rapids</th><th colspan="4">Bluefish</th></tr>
<tr><th>Number of Surveys</th><th>Start</th><th>End</th><th>Location</th><th>Number of Surveys</th><th>Start</th><th>End</th></tr>
<tr><td rowspan="2">2013</td><td rowspan="2">6</td><td rowspan="2">09-Oct</td><td rowspan="2">12-Nov</td><td>Tailrace</td><td rowspan="2">7</td><td rowspan="2">13-Sep</td><td rowspan="2">12-Nov</td></tr>
<tr><td>Reach 1</td></tr>
<tr><td rowspan="2">2014</td><td rowspan="2">4</td><td rowspan="2">10-Oct</td><td rowspan="2">11-Nov</td><td>Tailrace</td><td>8</td><td rowspan="2">21-Aug</td><td rowspan="2">03-Nov</td></tr>
<tr><td>Reach 1</td><td>10</td></tr>
<tr><td rowspan="2">2015</td><td rowspan="2">2</td><td rowspan="2">15-Oct</td><td rowspan="2">22-Oct</td><td>Tailrace</td><td>9</td><td rowspan="2">09-Sep</td><td rowspan="2">05-Nov</td></tr>
<tr><td>Reach 1</td><td>11</td></tr>
<tr><td rowspan="2">2016</td><td rowspan="2">4</td><td rowspan="2">10-Oct</td><td rowspan="2">31-Oct</td><td>Tailrace</td><td rowspan="2">8</td><td rowspan="2">30-Aug</td><td rowspan="2">02-Nov</td></tr>
<tr><td>Reach 1</td></tr>
<tr><td rowspan="2">2017</td><td rowspan="2">4</td><td rowspan="2">06-Oct</td><td rowspan="2">31-Oct</td><td>Tailrace</td><td rowspan="2">8</td><td rowspan="2">06-Sep</td><td rowspan="2">08-Nov</td></tr>
<tr><td>Reach 1</td></tr>
<tr><td rowspan="2">2018</td><td rowspan="2">6</td><td rowspan="2">11-Oct</td><td rowspan="2">02-Nov</td><td>Tailrace</td><td rowspan="2">7</td><td rowspan="2">05-Sep</td><td rowspan="2">06-Nov</td></tr>
<tr><td>Reach 1</td></tr>
<tr><td rowspan="2">2019</td><td rowspan="2">4</td><td rowspan="2">10-Oct</td><td rowspan="2">25-Oct</td><td>Tailrace</td><td rowspan="2">6</td><td rowspan="2">01-Oct</td><td rowspan="2">06-Nov</td></tr>
<tr><td>Reach 1</td></tr>
<tr><td rowspan="2">2020</td><td rowspan="2">3</td><td rowspan="2">23-Oct</td><td rowspan="2">30-Oct</td><td>Tailrace</td><td rowspan="2">5</td><td rowspan="2">08-Oct</td><td rowspan="2">03-Nov</td></tr>
<tr><td>Reach 1</td></tr>
</table>

[1]A subset of snorkel surveys were funded through the NTPC Bluefish Fall Spawning Fish programs (Golder 2017, 2018, 2019)

Photo 11. A snorkeler (at arrow) counting fish in a back eddy below the first rapids at Tartan Rapids, Yellowknife River, Northwest Territories (October 29, 2018).

Photo 12. A school of Cisco at Bluefish Rapids, Yellowknife River, Northwest Territories (October 7, 2016).

2.5 ENVIRONMENTAL DATA SOURCES

2.5.1 Hydrometric and Temperature Data

Historical and real-time hydrometric discharge data were obtained from the ECCC to characterize the Yellowknife River Study Area (Figure 1). The sources of the data were the Historical Hydrometric Data web site (ECCC 2021b), Real-time Hydrometric Data web site for stations 07SC002 and 07SB003 (ECCC 2021a; ECCC 2021b), and from email communications with ECCC.

Hydrometric flow data for each station are summarized below.

- 07SB002 Yellowknife River at outlet of Prosperous Lake:
  - Historical mean daily discharge for period of record from 1937 to 2018 (ECCC 2021a);
  - Mean daily discharge for 2019 (Angus Pippy, Water Survey of Canada, pers. comm.); and
  - Real-time discharge in 15-minute intervals for 2020 (ECC2021b).
- 07SB003 Yellowknife River at inlet to Prosperous Lake:
  - Historical mean daily discharge for period of record from 1939 to 2018 (ECCC 2021a);
  - Mean daily discharge for 2019 (Angus Pippy, Water Survey of Canada, pers. comm.); and
  - Real-time discharge in 15-minute intervals for 2020 (ECC2021b).

The 2019 and 2020 data from ECCC are considered preliminary and have received limited verification and review for quality assurance. The hydrometric data were examined for gaps and errors prior to analyses and no concerns were identified (e.g., negative flow rates or flow rates an order of magnitude greater than the range of historical record).

2.5.2 Water Temperature

Raw mean daily water temperature data were received over email communications (Angus Pippy, Water Survey of Canada, pers. comm.)[2] from stations:

- 07SB014 Prosperous Lake Near McMeekan Bay, 1997–2020; and
- 07SB015 Bluefish Lake Near Yellowknife,1997–2020.

[2] Temperature records are collected as an auxiliary parameter by ECCC and remain in their raw data format; therefore, data were examined for gaps and errors prior to analyses. It was noted that data for station 07SB015 appeared to contain implausible data February 22-24, 2020 (i.e., water temperatures in February >30ºC) and were consequently removed from the dataset.

2.6 DATA ANALYSIS

2.6.1 Environmental Data

Hydrometric Data

Discharge and temperature data were compiled for the inlet and outlet of Prosperous Lake, corresponding to conditions at Bluefish and Tartan Rapids, respectively. Hydrometric data from 1999–2020 were examined for trends within and among years for seasonal cycles (year-round) and for trends specific to the study period (October 1–November 7). The analyses summarized real-time data in 15-minute intervals, converted to daily averages and combined with historical daily averages.

Water Temperature

Temperature data was analyzed from 2011 to 2020 using data from station 07SB014, as this station included the most complete record for the study period (compared to other nearby WSC stations). Missing temperature data for year 2014 and partial data for year 2015 were noted. Temperature data for station 07SB015 was analyzed from years 2006 to 2020 as it was the most complete period of record. Mean temperature of Prosperous Lake and Bluefish Lake were calculated for of the study period of October 1–November 7,1999–2020.

2.6.2 Indices of Relative Abundance

Sampling effort data collected on Cisco from the Yellowknife River from 1999 to 2020 were compiled, including catch-effort and snorkel survey observations (Table 1). Catch-effort data were summarized by sampling approach (commercial fishery or fishery-independent), gear type (dip net or gill net), and location (Tartan Rapids or Bluefish).

All data sources were reviewed for consistency, data entry errors, and missing data. The following data issue was identified and addressed to the extent possible:

- During the snorkel survey in 2015, on October 23 and November 5, two sets of times were recorded for the same snorkel pass. When compiling the data, the first time was used for calculations since the second time recorded was only used as a quality assurance snorkel pass in the field.

Cisco CPUE was summarized (i.e., sample size, mean, median, standard deviation [SD], standard error [SE], minimum, and maximum values) by sampling approach (i.e., commercial fishery or fishery-independent), site, and gear type. Relationships between annual median CPUE of the commercial fishery and environmental variables (i.e., water temperature and discharge) were examined using general linear models. Water temperature and discharge values used in the models were means from October 1–November 7, intended to encompass the Cisco spawning period. As age-at-maturity for Cisco has been estimated at 3–4 y (Muir et al. 2011), lag effects were also considered for both water temperature and discharge (October 1–November 7) over a 3 and 4 year period, to determine if there was a relationship with recruitment into the spawning stock biomass. Several models were examined with Akaike Information Criterion (AIC) to assess the relative quality of each model (Sakamoto 1986; Burnham and Anderson 2003). These analyses focused on CPUE records from the commercial fishery given larger sample sizes and because CPUE was calculated differently with the fishery-independent surveys.

2.6.3 Biological Data

Biological data collected from Cisco in the Yellowknife River from 1999 to 2020 were compiled and summarized by sampling approach (commercial fishery or fishery-independent), gear type (dip net or gill net), and location (Tartan Rapids or Bluefish) (Table 1).

All data sources were reviewed for consistency, data entry errors or implausible data (i.e., measurement values outside the expected range for the variables), and missing data. The following data issues were identified and addressed to the extent possible:

- The ages for 12 fish in 2014 were not assigned due to a discrepancy in sample numbers between biological and age estimation data.
- Maturity codes were assigned to fish captured in 2013 as they were not assigned a DFO maturity code when processed but were labelled as either “Mature” or “Immature” (Appendix 2).
- Not all samples from 2010 and 2011 were assigned a capture date and therefore in some cases had to be grouped as one year.

Fork length, round weight, age, gonad weight, and liver weight were summarized (i.e., sample size, mean, median, SD, SE, minimum, and maximum) separately for females and males and the pooled sample, by site, gear type, and year. Comparisons excluded Cisco that were not assigned to a specific year (i.e., the 2010 & 2011 samples). When possible, the following metrics were calculated:

$$Fulton's\ condition\ factor\ (k) = \left(\frac{round\ weight}{fork\ length^3}\right) \times 100{,}000$$

$$Gonadosomatic\ index\ (GSI) = \left(\frac{gonad\ weight}{round\ weight}\right) \times 100$$

$$Liver\ somatic\ index\ (LSI) = \left(\frac{liver\ weight}{round\ weight}\right) \times 100$$

With weight and length measurements reported in units of grams (g) and millimeters (mm), respectively.

Biological data were examined visually using boxplots; length and age were also presented by year using length- and age-frequency distributions. Inferential statistics were used to assess whether there were differences in the biological characteristics of fork length, weight, and age among sample groups of survey, gear type, and location to determine whether samples could be pooled to maximize sample size used in the analyses. As the sample groups were not fully crossed (i.e., Cisco were not collected from all combination of survey approach, gear type, and location), each variable was examined separately using either a two- or three-way analysis of variance (ANOVA) with year included as a factor, as well as the interaction term between each variable and year.

Once suitable groupings were identified, ANOVA was used to compare and contrast biological data among the remaining factors. To assess relative differences in body and organ weights, covariates were included in these analyses where appropriate (i.e., length and weight). Statistical outliers were evaluated using studentized residuals (SR) from the ANOVA models. A magnitude of 3.5 for the SR was used to identify unusual observations (as per Dohoo et al. 2009). When an outlier was detected, the validity of the value was examined. If the outlier was determined to be the result of data entry error, the error was corrected; if the outlier was not the result of data entry error and could not be resolved otherwise, the outlier was removed from the analysis and documented.

Due to large sample sizes used in statistical comparisons (n >2,000), statistical significance was observed for most interactions, including differences that may not be biologically meaningful. When a significant interaction was observed, the results were compared between the full regression model including the interaction terms, and the reduced model excluding the interaction terms. If the interaction terms explained less than 2% of the observed variance (i.e., the differences in R^2 values between the full and reduced models), the reduced model was used, under the assumption that the regression slopes between groups were practically similar (Barrett et al., 2010).

When significant differences were detected between groups, the magnitude of differences was calculated for each variable by expressing the difference as a percentage of the mean as follows:

$$Magnitude = \frac{\bar{x}_{Group1} - \bar{x}_{Group2}}{\bar{x}_{Group2}} * 100$$

Where $\bar{x}$ was the mean of the parameter, and $Group_1$ and $Group_2$ refers to the two groups being compared. If the statistical comparison was conducted on $\log_{10}$-transformed data, then the magnitude was calculated using geometric means. When significant interactions were detected, relative percent differences were calculated for each variable in each year.

In addition to ANOVA, the Mann-Kendall test was used to identify temporal trends in annual means of biological data. The Mann-Kendall test is a non-parametric method used to determine whether time series data exhibit a monotonic upward or downward trend over time. Sex ratios were compared among years using the chi-square test.

Length-Weight Relationship

A power regression was used to describe the relationship between fish length and weight:

$$W = aL^b$$

Where $W =$ weight (g) and $L =$ fork length (cm). Using the linear regression of the $\log_{10}$-transformed equation: log (W) = log (a) + b log (L), the parameters a and b were calculated with 'a' representing the intercept and 'b' the slope of the relationship. Length-weight equations were calculated for each sampling year. Length-weight relationships were calculated separately for males, females, and the total sample whenever possible; however, sex information was only available starting in 2010. Time-series trends in growth were examined using the Mann-Kendall test, and differences between sexes among years were compared using a paired t-test.

Von Bertalanffy Growth Model

To describe growth, a three parameter von Bertalanffy model was fit to length-at-age data using the equation:

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right)$$

where L_t is the length at age t, L_∞ is the asymptotic average length, K is the rate at which the fish approaches the asymptotic size (i.e., growth coefficient), and t_0 is the theoretical time when a fish has a length of zero. Annual growth rates were estimated by $L_\infty * K$ (Gallucci and Quinn 1979). One von Bertalanffy curve was fit to the entire dataset and separate von Bertalanffy curves were also fit to each year. The parameters L_∞ and K can be compared to assess differences in growth whereas t_0 is a modelling artefact and does not have a meaningful biological interpretation (Schnute and Fournier 1980). Results were only presented for years where model convergence was obtained.

3 RESULTS

3.1 ENVIRONMENTAL DATA

The average daily discharge of Prosperous Lake inlet from 1999–2020 was 29.3 m^3/s (Figure 4). The lowest daily discharge was 19.7 m^3/s on May 11 and the highest daily discharge was 37.8 m^3/s on July 31. The mean discharge at Prosperous Lake inlet during the study period (October 1–November 7) was 30.9 m^3/s, with the lowest recorded mean in 2015 (4.5 m^3/s) and the highest in 2001 (60.7 m^3/s) (Figure 5).

The average daily temperature of Bluefish Lake from 1999–2020 was 7.2°C (Figure 6) (with the exception of 1999 and 2002–2004, which were unavailable). The highest average daily temperature through the calendar year was 20.5°C on August 14. The mean temperature at Bluefish Lake during the study period was 7.8°C with the lowest recorded mean in 2005 (2.8°C) and the highest in 2012 (10.3°C) (Figure 7).

The average daily discharge at Prosperous Lake outlet from 1999–2020 was 36.6 m^3/s (Figure 4). The lowest average daily discharge through the calendar year was 23.6 m^3/s on May 6 and the highest average daily discharge was 47.0 m^3/s on July 30. Discharge was consistently greater at the outlet of Prosperous Lake compared to the inlet. The mean discharge at Prosperous Lake outlet during the study period was 37.9 m^3/s, with the lowest recorded mean in 2015 (5.2 m^3/s) and the highest in 2001 (80.8 m^3/s) (Figure 5).

The average daily temperature of Prosperous Lake from 1999–2020 was 6.1°C (Figure 6) (with the exception of 1999, 2001–2004, 2008–10, and 2014 which were unavailable). The highest average daily temperature through the calendar year was 18.8°C on August 14. The mean temperature at Prosperous Lake during the study period was 7.3°C, with the lowest recorded mean in 2005 (2.9°C) and the highest in 2012 (12.8°C) (Figure 7). The WSC station temperature was weakly correlated with discharge data for both Bluefish Rapids (Pearson $r= 0.01$) and Tartan Rapids (Pearson $r= -0.18$) during the study period.

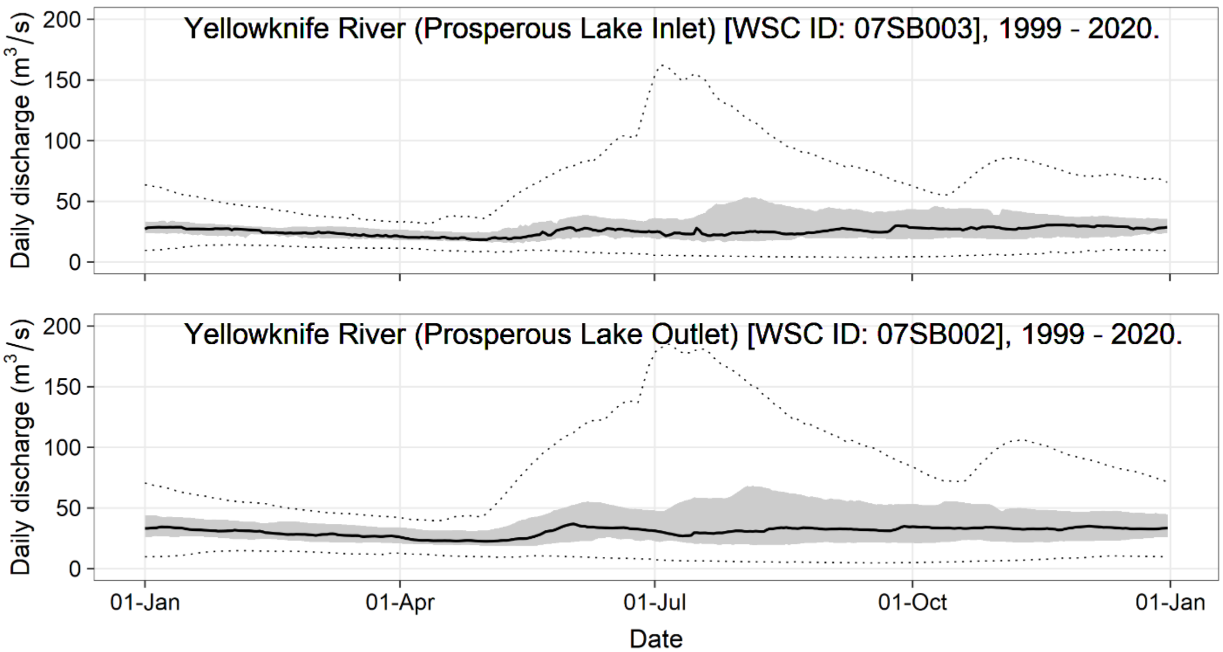


Figure 4. Median daily discharge (solid line) of the Yellowknife River at the inlet and outlet of Prosperous Lake, Northwest Territories, 1999–2020. The shaded area and dotted lines indicate the interquartile range, and minimum and maximum values of the unmodified data. Source: WSC (2020).

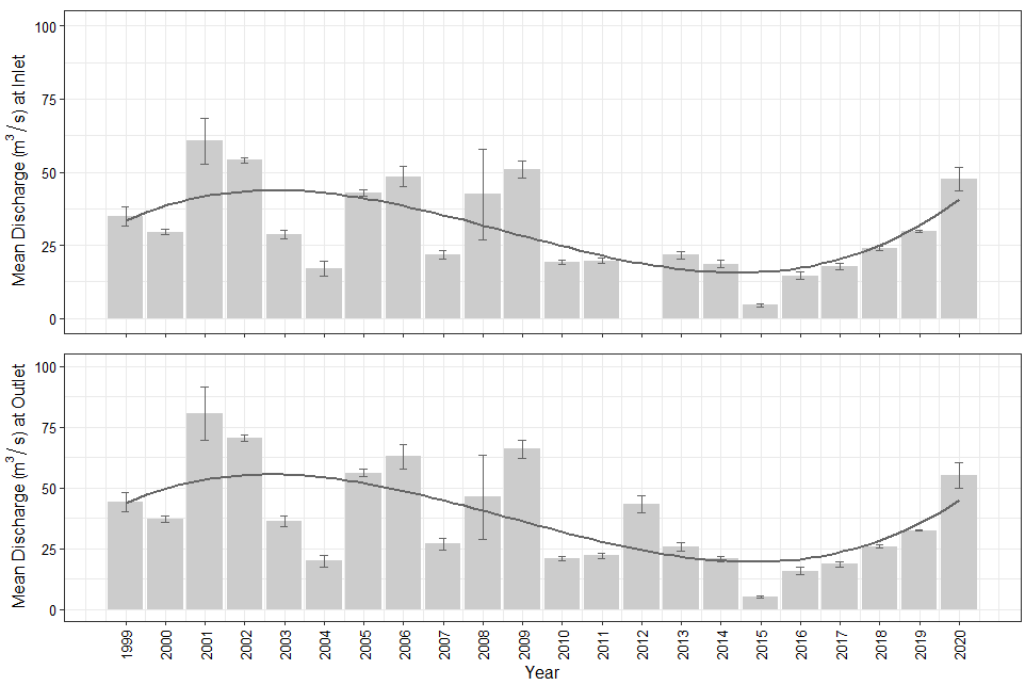


Figure 5. Annual mean daily discharge during the study period (October 1–November 7) *at Prosperous Lake inlet and outlet, 1999–2020. The line represents a third order polynomial regression line and error bars represent the standard deviation of the mean.*

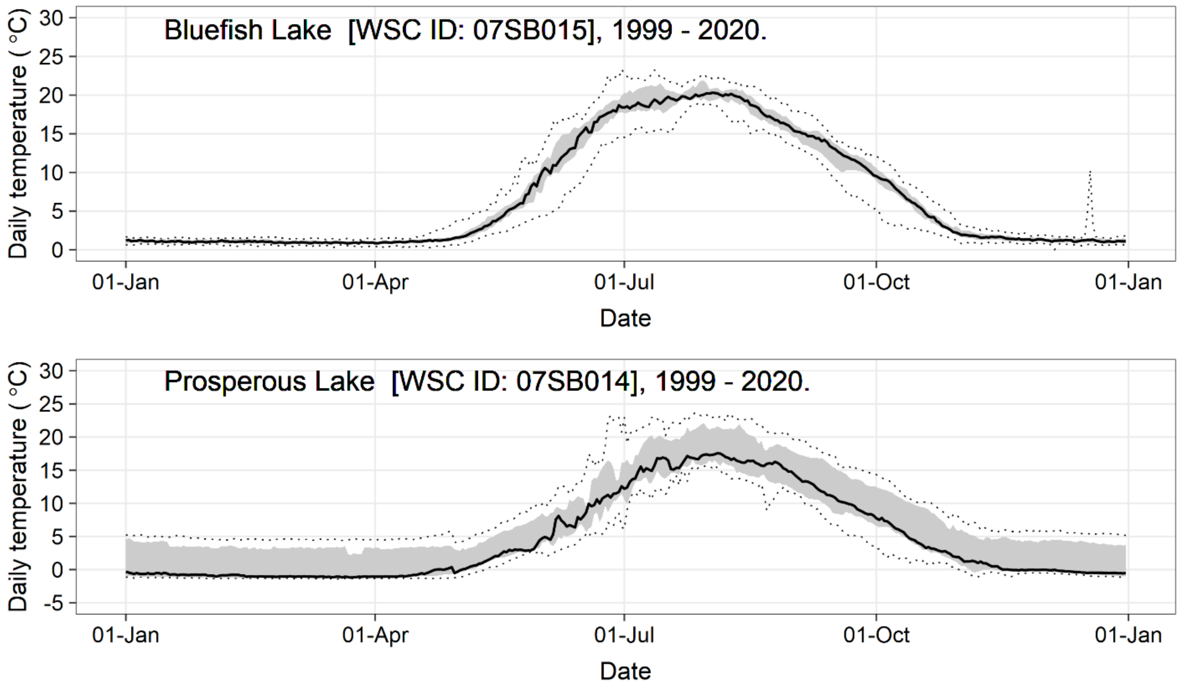


Figure 6. Median daily water temperature (solid line) of Prosperous and Bluefish lakes, Northwest Territories, 1999–2020. The shaded area and dotted lines indicate the interquartile range, and minimum and maximum values of the unmodified data. Source: WSC (2020).

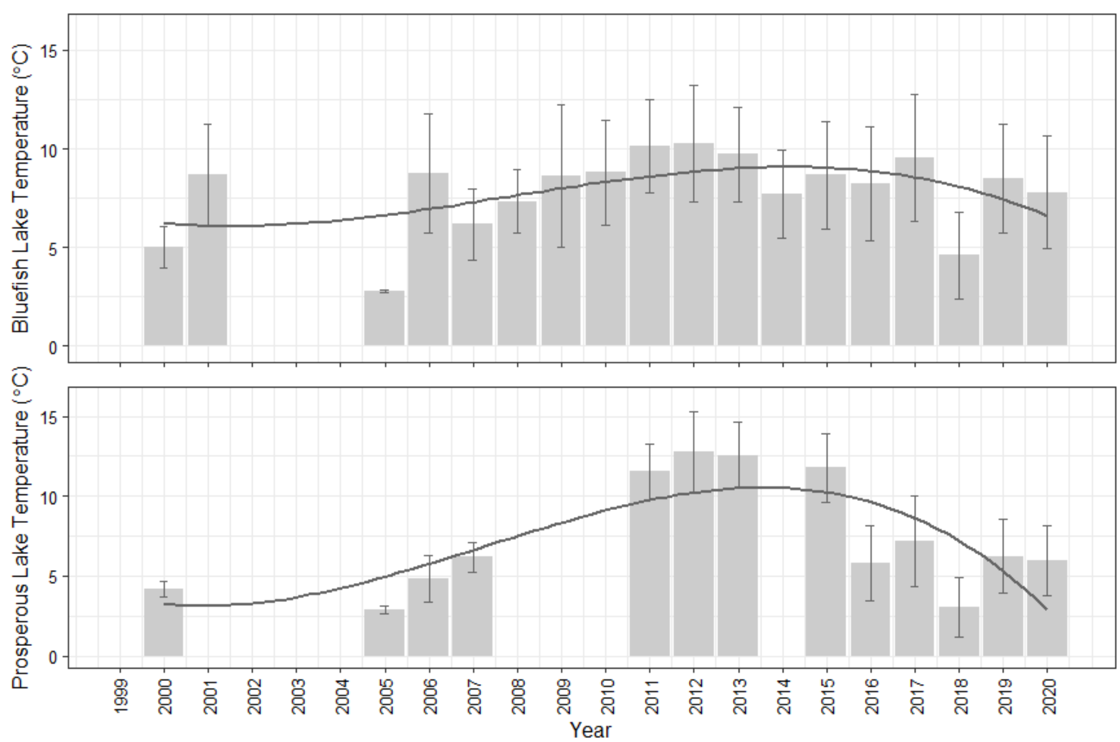


Figure 7. Annual mean daily water temperature during the study period (October 1–November 7) of Prosperous and Bluefish lakes, Northwest Territories, 1999–2020. The line represents a third order polynomial regression line and error bars represent the standard deviation of the mean.

3.2 COMMERCIAL FISHERY QUOTAS AND HARVEST

A single commercial fishing licence for Cisco was issued on an annual basis each fall for 1,000 kg from 1998–2002, 2,000 kg from 2004–2005, 1,000 kg from 2010–2018, and 1,500 kg from 2019–2020. The commercial fishery generally began in late-September to early-October and ended in late-October just prior to freeze-up. The estimated number of Cisco harvested each year ranged from 7,164 (2004) to 33,705 fish (2019), with fishing effort ranging from 4 hours (2004) to 58 hours (2016) (Table 3). Only four hours of fishing effort were recorded in 2004 due to illness and weather delays. Because the total biomass is estimated (based on the number of fish and/or bags and average weight for that year), it is important to note that values exceeding the issued quota do not necessarily represent an overharvest. Generally, in most years when the commercial harvest occurred, the fisher caught close to the quota issued.

Table 3. Quota issued, timing, effort, and harvest of Cisco captured by dip nets in the commercial fishery at Tartan Rapids, Yellowknife River, Northwest Territories, 1998–2020.

Year	Quota (kg) /Year	Start	End	Hours Fished	Number of Bags[(a)]	Number of Cisco Harvested [(b)]	Estimated Biomass Harvested[(c)] (kg)	Average CPUE (Cisco/h ± SD)
1998	1,000	-	-	-	-	16,423	900	-
1999	1,000	25 Sep	12 Oct	30	-	15,204	932	574 (± 461)
2000	1,000	26 Sep	07 Oct	-	-	16,380	878	-
2001	1,000	29 Sep	12 Oct	27.5	-	20,568	1,095	847 (± 452)
2002	1,000	08 Oct	24 Oct	12	-	24,060	1,223	2,162 (± 1543)
2003[(d)]	-	-	-	-	-	-	-	-
2004	2,000	11 Oct	17 Oct	4	-	7,164	327	1,791 (± 846)
2005	2,000	26 Sep	30 Oct	46	-	39,744	2,009	962 (± 623)
2006	0							
2007	0							
2008	0							
2009	0							
2010	1,000	23 Oct	31 Oct	22	1,852	11,112	618	634 (± 595)
2011	1,000	07 Oct	17 Oct	-	2,145	12,870	615	-
2012	1,000	03 Oct	18 Oct	23.5	4,400	26,400	1,152	993 (± 482)
2013	1,000	06 Oct	24 Oct	37	3,086	18,516	912	490 (± 192)
2014	1,000	03 Oct	16 Oct	25	2,135	21,350	1,196	984 (± 914)
2015	1,000	05 Oct	16 Oct	20	1,303	13,030	748	662 (± 382)
2016	1,000	19 Sep	22 Oct	58	2,122	21,220	1,264	332 (± 212)
2017	1,000	07 Oct	20 Oct	57	2,944	26,196	1,265	449 (± 230)
2018	1,000	27 Sep	11 Oct	42	2,124	20,240	1,011	500 (± 289)
2019	1,500	29 Sep	14 Oct	50	3,745	33,705	1,598	611 (± 456)
2020	1,500	10 Oct	19 Oct	19	3,163	28,467	1,388	1,314 (± 1006)

(a) 2010–2013 = six Cisco/bag, 2014–2020 = 9 to 10 Cisco/bag; (b) in some cases this may be an estimate; (c) estimated biomass was calculated as the mean weight of fish from that year multiplied by the number of fish harvested; (d) records from 2003 commercial harvest could not be located but biological samples were collected October 1–12; - data not available.

3.3 INDICES OF RELATIVE ABUNDANCE

3.3.1 Commercial Fishery

CPUE in the commercial fishery was variable within and among years (Figure 8, Figure 9), with median CPUE ranging from 415 Cisco/h in 2010 to 1,998 Cisco/h in 2004 (Table 4). CPUE in the commercial fishery appeared relatively consistent (i.e., between ~400 and 1,000 Cisco/h) apart from the years with relatively higher (>1,500 Cisco/h) medians (2002, 2004, 2005, 2012, and 2020). CPUE was generally lowest earlier in the season and improved throughout October, likely reflecting the increasing abundance of migrating Cisco during this period of time.

The general linear models used to examine the relationship between mean river discharge and temperature, October 1–November 7, and annual median CPUE (Table 4) demonstrated that the lowest prediction error of the specified models for estimating CPUE (i.e., the lowest AIC) included temperature and discharge within a given year (Table 5, Table 6). The model was statistically significant, explaining 83% of the observed variance, with CPUE increasing with both temperature and discharge, suggesting these conditions were more conducive to capturing Cisco at the Tartan Rapids. Based on this model, optimal condition for maximizing CPUE occurred when average water temperatures during the spawning period were 10–15 °C and/or discharge was 35–55 m^3/s (e.g., 2012). The models with the next lowest AIC values included temperature and discharge incorporating a three to four year lag period, suggesting past environmental conditions may also contribute to variability in recruitment and CPUE; however, AIC values were considerably greater, indicating relatively poor predictive capacity and model fit (Burnham and Anderson 2003).

Table 4. Cisco catch-per-unit-effort (fish/hour) of Cisco from the commercial fishery at Tartan Rapids, Yellowknife River, Northwest Territories and mean temperature and discharge during the spawning migration from October 1–November 7, 1999–2020.

Year	Sample Size	Catch-Per-Unit-Effort						Mean Discharge (m^3/s)	Mean Water Temperature (°C)
		Mean	Median	SD	SE	Min	Max		
1999	12	574	600	461	133	42	1,668	44.41	-
2001	13	847	896	452	125	240	1,590	80.79	-
2002	8	2,162	1,674	1,543	546	516	5,556	70.57	-
2004	4	1,791	1,998	846	423	600	2,568	19.94	-
2005	21	962	979	623	136	240	2,400	56.26	2.87
2010	6	634	415	595	243	228	1,821	20.84	-
2012	11	993	1,148	482	145	144	1,784	43.54	12.78
2013	12	490	541	192	55	150	700	25.91	12.58
2014	11	984	675	914	276	167	3,300	20.85	-
2015	8	662	601	382	135	250	1,500	5.23	11.77
2016	18	332	425	213	50	0	767	15.94	5.81
2017	13	449	441	230	64	50	797	18.79	7.19
2018	11	500	450	289	87	80	1,063	26.00	3.05
2019	14	611	560	457	122	33	1,451	32.62	6.23
2020	12	1,314	1,076	1,007	291	40	3,812	55.13	5.98

Sample size= number of fishing events (each on separate day); SD = standard deviation; SE = standard error; Min = minimum; Max = maximum, - unavailable.

Table 5. Coefficient of determination and Akaike information criterion of various models exploring relationships among median CPUE and annual mean for river temperature and discharge (October 1–November 7), 1999–2020.

Model	AIC	AIC Weight
CPUE ~ Temperature (-0 y) + Discharge (-0 y)	-0.1	0.9399
CPUE ~ Temperature (-3 y) + Discharge (-4 y)	8.2	0.0150
CPUE ~ Temperature (-0 y) + Temperature (-3 y)	8.2	0.0145
CPUE ~ Temperature (-3 y)	9.2	0.0088
CPUE ~ Discharge (-0 y) + Discharge (-3 y)	10.4	0.0049
CPUE ~ Temperature (-0 y) + Discharge (-4 y)	10.6	0.0043
CPUE ~ Temperature (-0 y) + Discharge (-3 y)	11.0	0.0035
CPUE ~ Temperature (-3 y) + Discharge (-3 y)	11.2	0.0033
CPUE ~ Temperature (-4 y) + Discharge (-3 y)	11.8	0.0024
CPUE ~ Temperature (-4 y) + Discharge (-4 y)	12.8	0.0015
CPUE ~ Temperature (-0 y)	13.7	<0.001
CPUE ~ Temperature (-4 y)	14.2	<0.001
CPUE ~ Discharge (-3 y)	17.0	<0.001
CPUE ~ Discharge (-0 y)	22.0	<0.001
CPUE ~ Ø	24.9	<0.001
CPUE ~ Discharge (-4 y)	27.0	<0.001

Note: Negative values indicate lag time expressed in years. For example -3 would indicate values recorded 3 years prior to the corresponding CPUE value.
AIC = Akaike information Criterion; R^2 = coefficient of determination; Ø = null model.

Table 6. Coefficients for the general linear model with the lowest estimate of prediction error (AIC) exploring relationships among CPUE and annual mean for environmental variables, 1999–2020.

Coefficients	Estimate	Standard Error	t value	*P* value
Intercept	-43.04	163.12	-0.264	0.801
Temperature (°C)	32.18	13.35	2.411	0.052
Discharge (m^3/s)	15.79	2.94	5.371	0.002

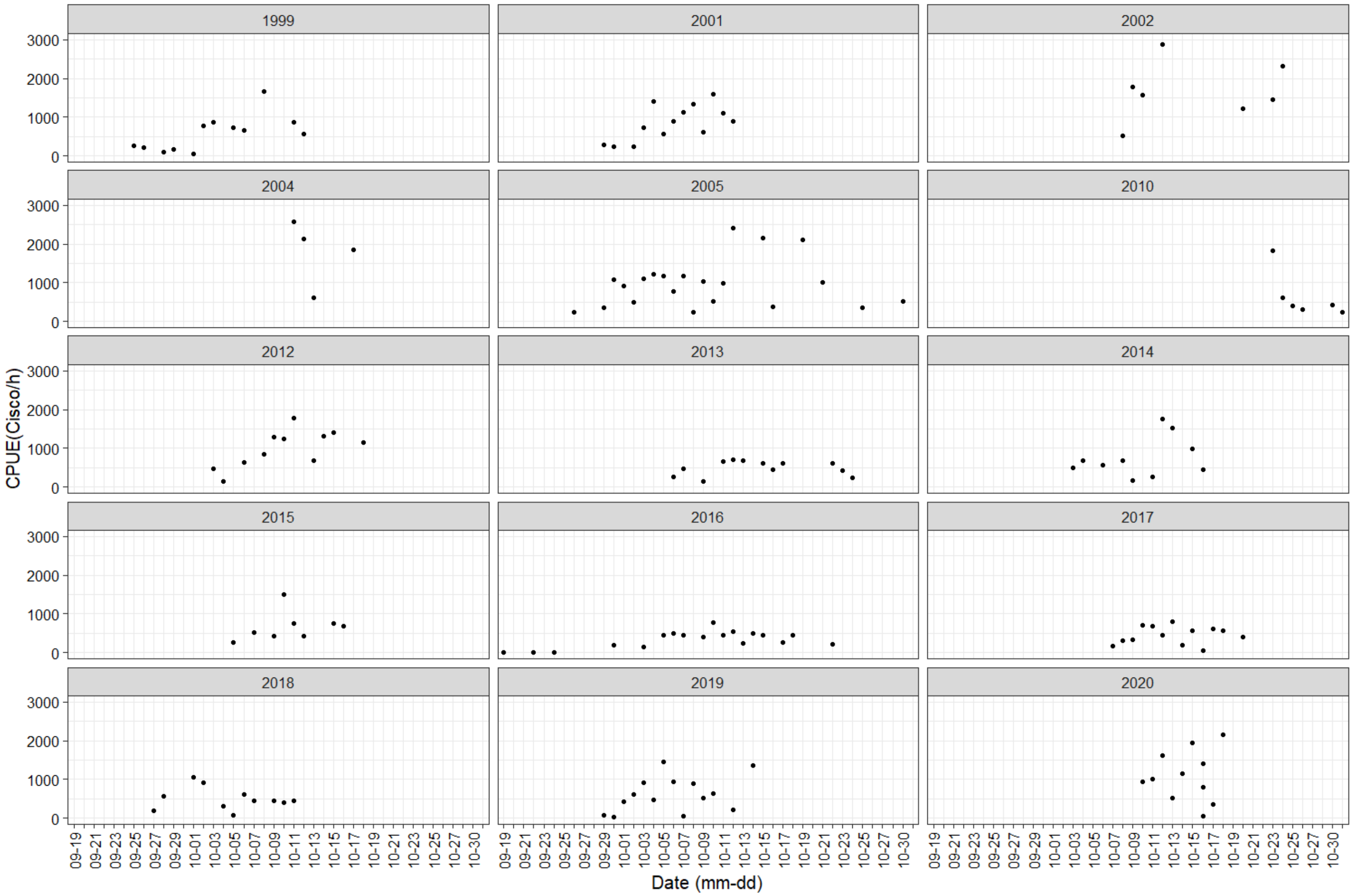


Figure 8. Daily catch-per-unit-effort (CPUE) for Cisco captured in dip nets during the commercial fishery at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020. Note: Three CPUE values were removed to improve data visualization: 5,556 (11-Oct-2002), 3,300 (10-Oct-2014), and 3,811 (19-Oct-2020).

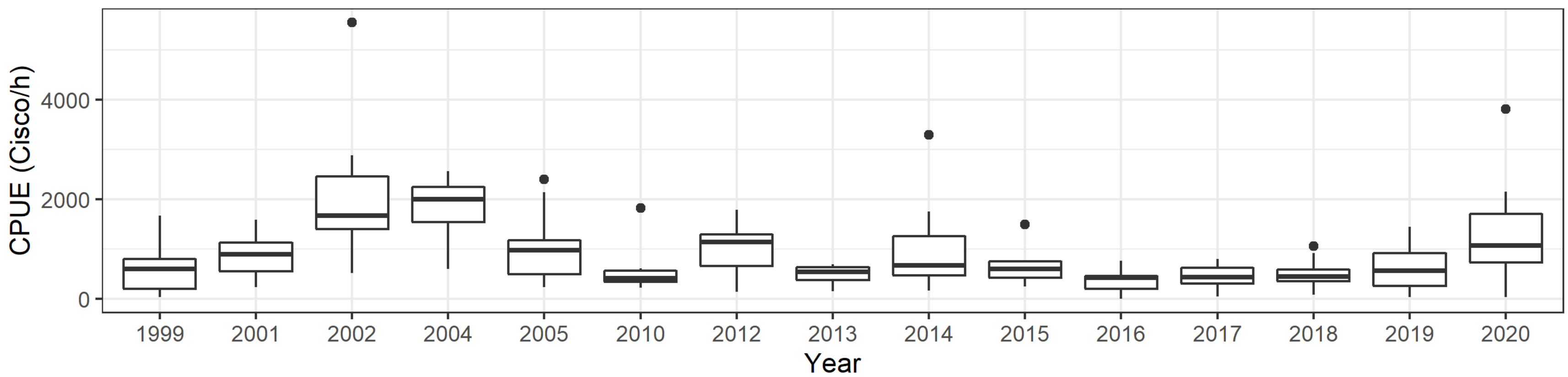


Figure 9. Catch-per-unit-effort (CPUE) box plots (median, quartiles, outliers (● values ≥1.5 x IQR)) for Cisco captured in dip nets during the commercial fishery at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020.

3.3.2 Fishery-Independent Sampling

CPUE between 2013 and 2020 was typically higher at Tartan Rapids compared to Bluefish regardless of gear type, with dip nets being more effective than gill nets (Table 7). Although CPUE was calculated differently between gear types, there was consensus in observations among field biologists that the dip net method was the most effective technique for sampling Cisco at Tartan Rapids.

The highest CPUE was observed from the Tartan Rapids dip nets in 2019, where 142 fish were captured by two fishers (biologists) in 2 minutes (CPUE= 2,130 fish/net/h). Regarding temporal trends, a decline was observed in the efficacy of dip nets over time at Bluefish. A declining trend in CPUE was not observed based on gill nets or dip nets at Tartan Rapids (Table 7).

Table 7. Catch-per-unit-effort (CPUE) of Cisco captured by fishery-independent sampling at Bluefish and Tartan Rapids, Yellowknife River, Northwest Territories, 2013–2020. CPUE was calculated as # fish/net/h for gill nets and # fish/net/h for dip nets.

Site	Gear	Year	Sampling Efforts	Catch-Per-Unit-Effort					
				Mean	Median	SD	SE	Min	Max
Bluefish	Dip net	2014	2	240	240	339	240	0	480
		2015	1	75	75	-	-	75	75
		2016	3	32	12	38	22	8	75
		2017(a)	1	38	38	-	-	38	38
		2018	1	0	0	-	-	0	0
	Gill net	2013	5	0	0	0	0	0	0
		2014	1	0	0	-	-	0	0
		2015	1	33	33	-	-	33	33
		2016	1	43	43	-	-	43	43
		2018	2	3	3	5	3	0	7
		2019	1	0	0	-	-	0	0
		2020	7	3	0	7	3	0	20
Tartan Rapids	Dip net	2014(a)	3	60	40	53	31	20	120
		2015(a)	0	-	-	-	-	-	-
		2016	4	42	42	18	9	23	63
		2017(a)	1	22	22	-	-	22	22
		2018	4	122	70	153	76	5	342
		2019	2	1,735	1,735	559	395	1,340	2,130
		2020	7	99	68	92	35	26	291
	Gill net	2013	4	2	1	2	1	0	5
		2014	1	7	7	-	-	7	7
		2015	1	90	90	-	-	90	90

(a) Effort duration not recorded for one or more efforts and CPUE could not be calculated.

SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; - not applicable.

3.3.3 Snorkel Surveys

The annual number of Cisco observed at Tartan Rapids ranged from 4,150 (2015) to 23,811 (2017) fish, based on 2–6 surveys conducted each fall (Table 8, Figure 10). The highest rate of Cisco observations occurred in 2017 with 7,884 Cisco/h and the lowest rate occurred in 2014 with 454 Cisco/h. The number of Cisco observed per hour exhibited a weak negative correlation with the number of Cisco captured per hour in the commercial fishery (Pearson $r = -0.42$) (Figure 11). Lake Whitefish were observed in all years, varying between 16 (2014) and 2,871 (2018) over the course of the surveys (Table 8).

The number of Cisco observed at Bluefish in Reach 1 varied from 0 (2017 and 2018) to 2,554 (2014) based on 5–11 surveys conducted each fall (Table 9, Figure 12). The number of Cisco observed at Bluefish in the Tailrace Area ranged from 149 (2020) to >10,000 (2013 and 2015) fish based on 5–9 surveys conducted each fall. The largest number of Cisco observed occurred in 2013 with 12,828 Cisco/h, and the lowest occurred in 2019 with 28 Cisco/h. Lake Whitefish were observed in all years at Bluefish, ranging between 305 and >10,000 fish annually (Table 9).

Table 8. Snorkel survey effort and fish observed at Tartan Rapids, Yellowknife River, Northwest Territories, 2013–2020.

Survey Effort					Fish Observations(a)			Lead Snorkeler Initials(b)
Year	# of Surveys	Start	End	Hours	CISC	LKWH	# of Cisco Observed/Hour	
2013	6	09-Oct	12-Nov	3.18	16,010	163	4,050*	PV
2014	4	10-Oct	11-Nov	8.17	3,711	16	454	PV
2015	2	15-Oct	22-Oct	-	4,150	348	-	PV
2016	4	10-Oct	31-Oct	4.5	7,221	1,736	1,605	PV
2017	4	06-Oct	31-Oct	3.02	23,811	1,891	7,884	PV
2018	6	11-Oct	02-Nov	7.35	10,414	2,871	1,417	FL
2019	4	10-Oct	25-Oct	3.8	16,129	994	4,244	MR
2020	3	23-Oct	30-Oct	3.38	5,461	848	1,616	MR

(a) CISC = Cisco; LKWH = Lake Whitefish; ; (b) PV= P. Vescei, FL= F. Larouche and MR= M. Redmond; - data not available; visual estimates were made when large numbers of fish were present *removed 3,130 fish from the total because no hours were associated with the observation.

Table 9. Snorkel survey effort and fish observed at Bluefish Rapids and Tailrace Area (Bluefish), Yellowknife River, Northwest Territories, 2013–2020.

Survey Effort						Fish Observations (a)			Lead Snorkeler Initials(d)
Year	Site (b)	# of Surveys	Start	End	Hours	CISC	LKWH	# of Cisco Observed/ Hour	
2013	Reach 1	7	13-Sep	12-Nov	0.92	1,802	388	12,828	PV
	Tailrace					>10,000(c)	326		
2014	Reach 1	10	21-Aug	03-Nov	5	2,554	1,080	1,135	PV
	Tailrace	8				3,120	921		
2015	Reach 1	11	09-Sep	05-Nov	2	269	1,708	5,135	PV
	Tailrace	9				>10,000	>10,000		
2016	Reach 1	8	30-Aug	02-Nov	13.7	716	1,218	755	PV
	Tailrace					9,631	1,596		
2017	Reach 1	8	06-Sep	08-Nov	9.43	0	305	578	PV
	Tailrace					5,450	3,155		
2018	Reach 1	7	05-Sep	06-Nov	2.15	0	185	342	FL
	Tailrace					736	1,478		
2019	Reach 1	6	01-Oct	06-Nov	9.47	105	1,020	28	MR
	Tailrace					163	936		
2020	Reach 1	5	08-Oct	03-Nov	6.85	299	735	65	MR
	Tailrace					149	205		

(a)CISC = Cisco; LKWH = Lake Whitefish; visual estimates were made when large numbers of fish were present (b)Snorkeling visits of Reach 1 and the Tailrace Area were conducted concurrently; (c)Snorkeler initially recorded over 100,000 fish at the Tailrace Area during a survey on October 17 2013, however, this number was adjusted to 10,000 fish for calculations; caution should be applied for any comparisons to the 2013 Cisco data; (d) PV= P. Vescei, FL= F. Larouche and MR= M. Redmond.

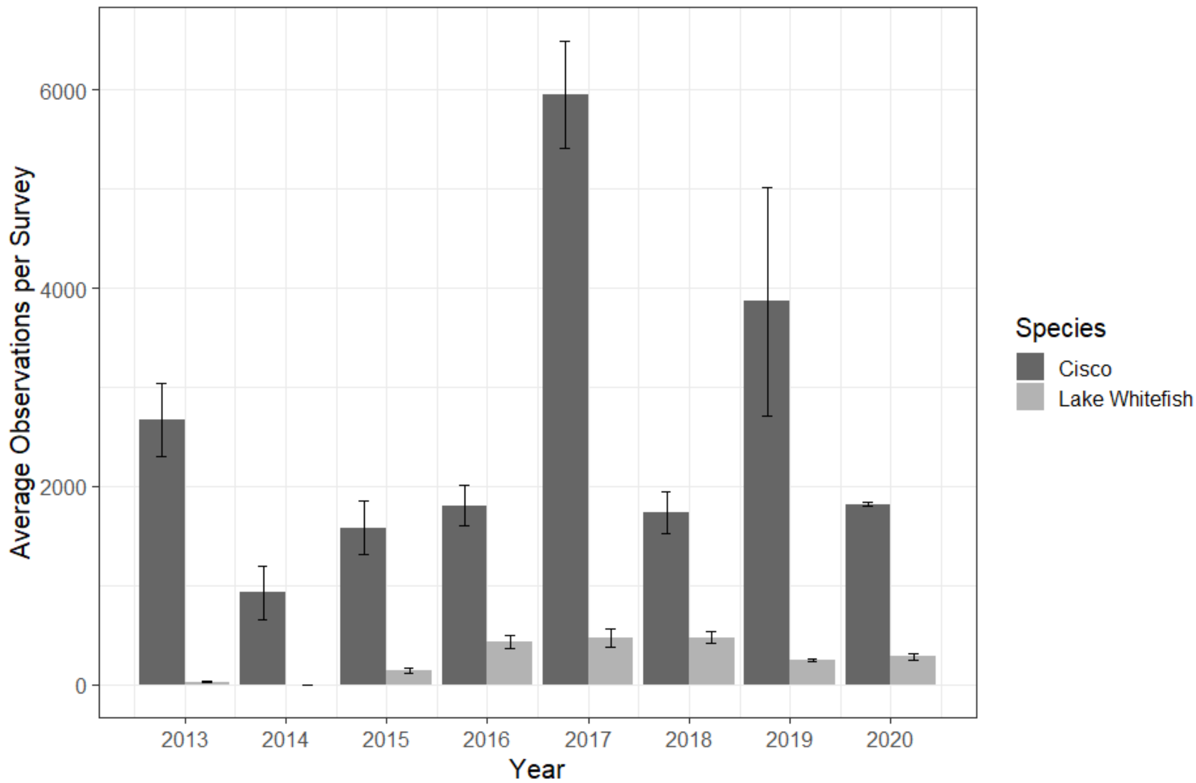


Figure 10. Average (±SE) number of Cisco and Lake Whitefish observed per snorkel survey at Tartan Rapids, Yellowknife River, Northwest Territories, 2013–2020.

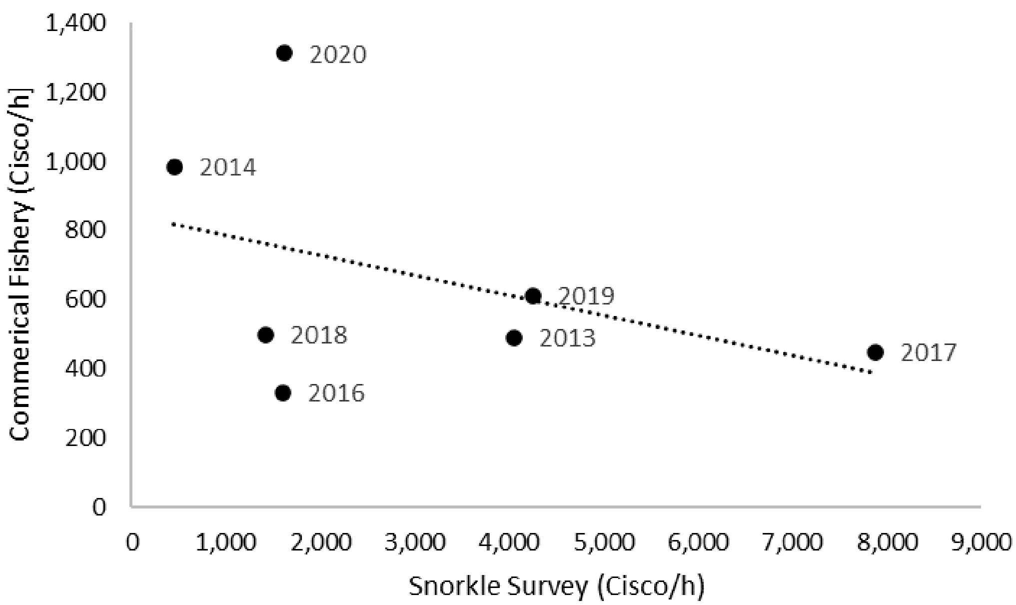


Figure 11. Relationship of relative abundance (Cisco/h) between the commercial fishery and the snorkel surveys at Tartan Rapids, Yellowknife River, Northwest Territories, 2013–2020.

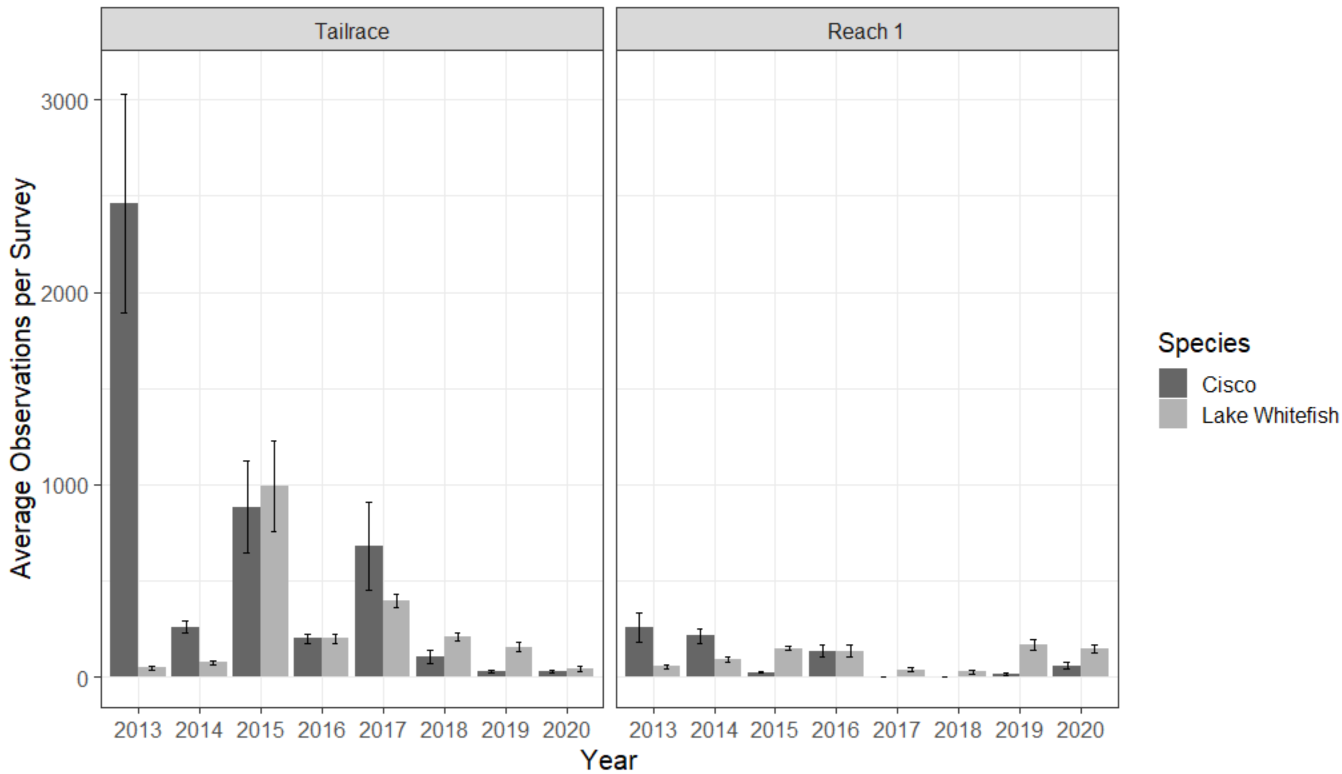


Figure 12. Average (±SE) number of Cisco and Lake Whitefish observed per snorkel survey at Tailrace and Reach 1 (Bluefish), Yellowknife River, Northwest Territories, 2013–2020.

3.4 BIOLOGICAL DATA

A total of 3,774 Cisco were sampled from the Yellowknife River from 1999–2020. Of these, the majority were sampled from Tartan Rapids (3,421 fish versus 353 sampled from Bluefish). At the Tartan Rapids, 3,367 fish were captured with dip nets and 54 with gill nets. Of the fish captured from the Tartan Rapids using dip nets, 2,484 Cisco were sampled through the commercial fishery, with the remaining 883 fish collected during fishery-independent sampling. At Bluefish, 260 fish were captured using dip nets and 93 with gill nets.

No statistically significant differences were observed in fish length or weight between the commercial fishery and fishery-independent sampling for Cisco captured using dip nets from the Tartan Rapids (Table A3.1, Figure A3.1). Statistically significant differences were observed in fish age; however, the magnitude of these differences were small (i.e., 0.2 years). Therefore, the commercial fishery and fishery-independent samples were pooled for Cisco captured using dip nets from the Tartan Rapids during subsequent comparisons. As these fish were collected using methods comparable to the commercial fishery and comprised the majority of fish sampled from the Yellowknife River (89%), all biological data presented below are focused on Cisco collected by dip net at Tartan Rapids, unless specified otherwise. Significant differences were observed among sites, gear types and sexes, and results were described separately with respect to these factors (Table A3.1, Table A3.2, Figure A3.2, Figure A3.3).

3.4.1 Size

Cisco fork length ranged from 102 mm to 239 mm, with most distributed between 160 mm and 190 mm (Table A3.2, Figure 13, Figure 14, Figure 15). Cisco total length ranged from 89 mm to 270 mm (Appendix A3.1). Cisco weight ranged from 10 g to 139.6 g, with most distributed between 40 g and 70 g (Table A3.2, Figure 13, Figure 14). Although significant differences in fish length and weight were observed among years (Table A3.1), length-frequency distributions were generally similar, with fish exhibiting unimodal distributions that did not exhibit any trends over time for the total sample or males and females separately (Table 10, Figure 13, Figure 14, Figure 15). Females were typically larger than males by length (4% longer or by 6.0 mm on average) and weight (18% heavier or by 8.5 g, on average) (Figure 14).

Cisco captured from Bluefish were generally larger (4% longer, or by 6.5 mm, on average) and heavier (12% heavier, or 6.1 g, on average) than Cisco caught at Tartan Rapids (Table A3.2, Table A3.3, Figure A3.2, Figure A3.3). While there was no significant differences in length between gear type detected, Cisco captured in dip nets were 4% heavier (2.3 g) than individuals captured with gill nets (Table A3.2).

3.4.2 Age

Cisco ranged in age from 1 to 9 years, with the majority between 3 and 6 years (Figure 13, Figure 14, Figure 16). While significant differences in fish age were observed among years (Table A3.1), no trends were observed over time. Cisco typically exhibited a left-skewed unimodal distribution and were dominated by 3 and 4 year old fish at the time of sampling (Figure 16). Female Cisco were significantly older (on average by 11% or 0.4 years) than males (Table A3.2, Table A3.3, Figure 14). Cisco captured using dip nets were 5% (0.2 yrs) older on average, than individuals captured with gill nets (Table A3.2).

Table 10. Mann-Kendall time-series trend analyses of biological data from Cisco captured using dip nets from Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020. Note: statistically significant trends indicated in ***bold.***

Parameter	Years	Tau	Slope	*P*-value
All fish				
Fork Length (mm)	1999–2020	-0.059	-0.097	0.762
Round Weight (g)	1999–2020	-0.098	-0.099	0.596
Condition Factor	1999–2020	-0.046	-0.001	0.820
Age (y)	1999–2020	-0.333	-0.047	0.079
Male				
Fork Length (mm)	2010–2020	-0.200	-0.362	0.436
Round Weight (g)	2010–2020	0.127	0.115	0.640
Condition Factor	2010–2020	0.745	0.009	**0.002**
Age (y)	2010–2020	-0.689	-0.133	**0.007**
Gonad Weight (g)	2013–2020	-0.333	-0.009	0.414
Gonadosomatic Index	2013–2020	-0.067	-0.001	0.906
Liver Weight (g)	2018–2020	-0.333	-0.025	1.000
Liversomatic Index	2018–2020	-1.000	-0.041	0.333
Female				
Fork Length (mm)	2010–2020	-0.200	-0.489	0.436
Round Weight (g)	2010–2020	-0.018	-0.121	1.000
Condition Factor	2010–2020	0.673	0.010	**0.005**
Age (y)	2010–2020	-0.467	-0.161	0.074
Gonad Weight (g)	2013–2020	-0.333	-0.076	0.414
Gonadosomatic Index	2013–2020	-0.333	-0.118	0.414
Liver Weight (g)	2018–2020	-1.000	-0.165	0.333
Liversomatic Index	2018–2020	-1.000	-0.214	0.333

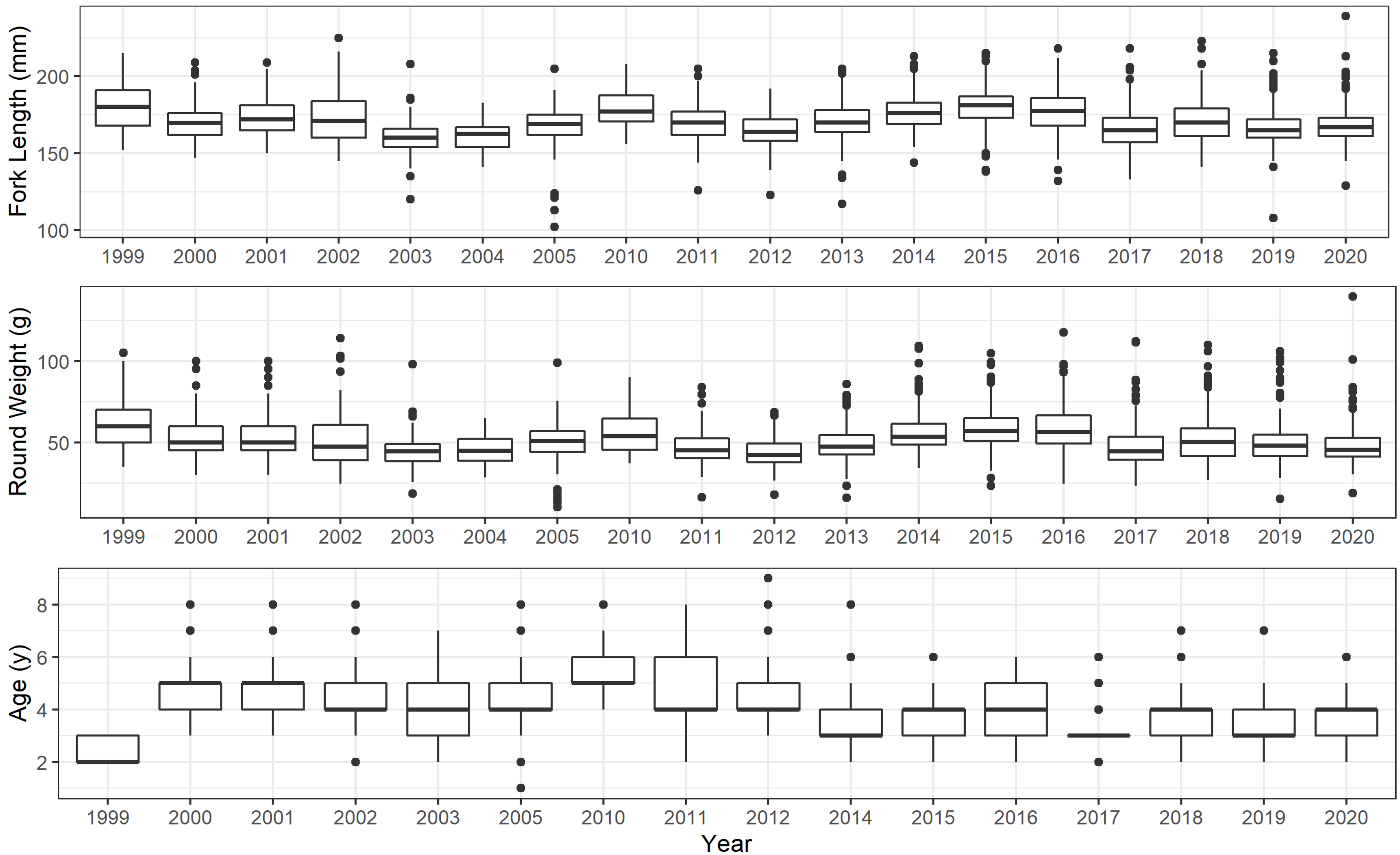


Figure 13. Fork length, round weight, and age box plots (median, quartiles, outliers [● values ≥1.5 x IQR]) for Cisco captured with dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020.

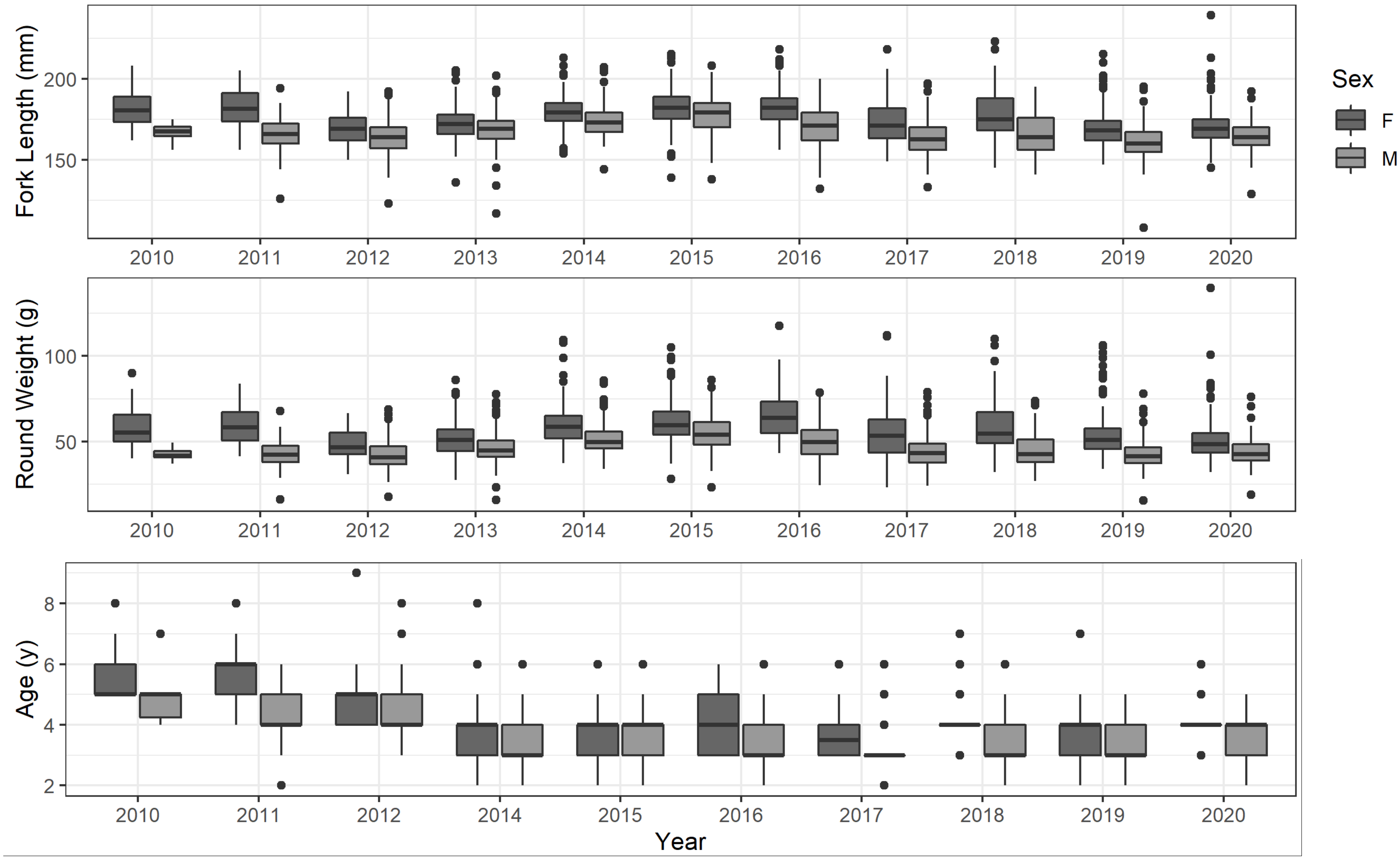


Figure 14. Fork length, round weight, and age box plots (median, quartiles, outliers [● values ≥1.5 x IQR]) of male (M) and female (F) Cisco captured with dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2010–2020.

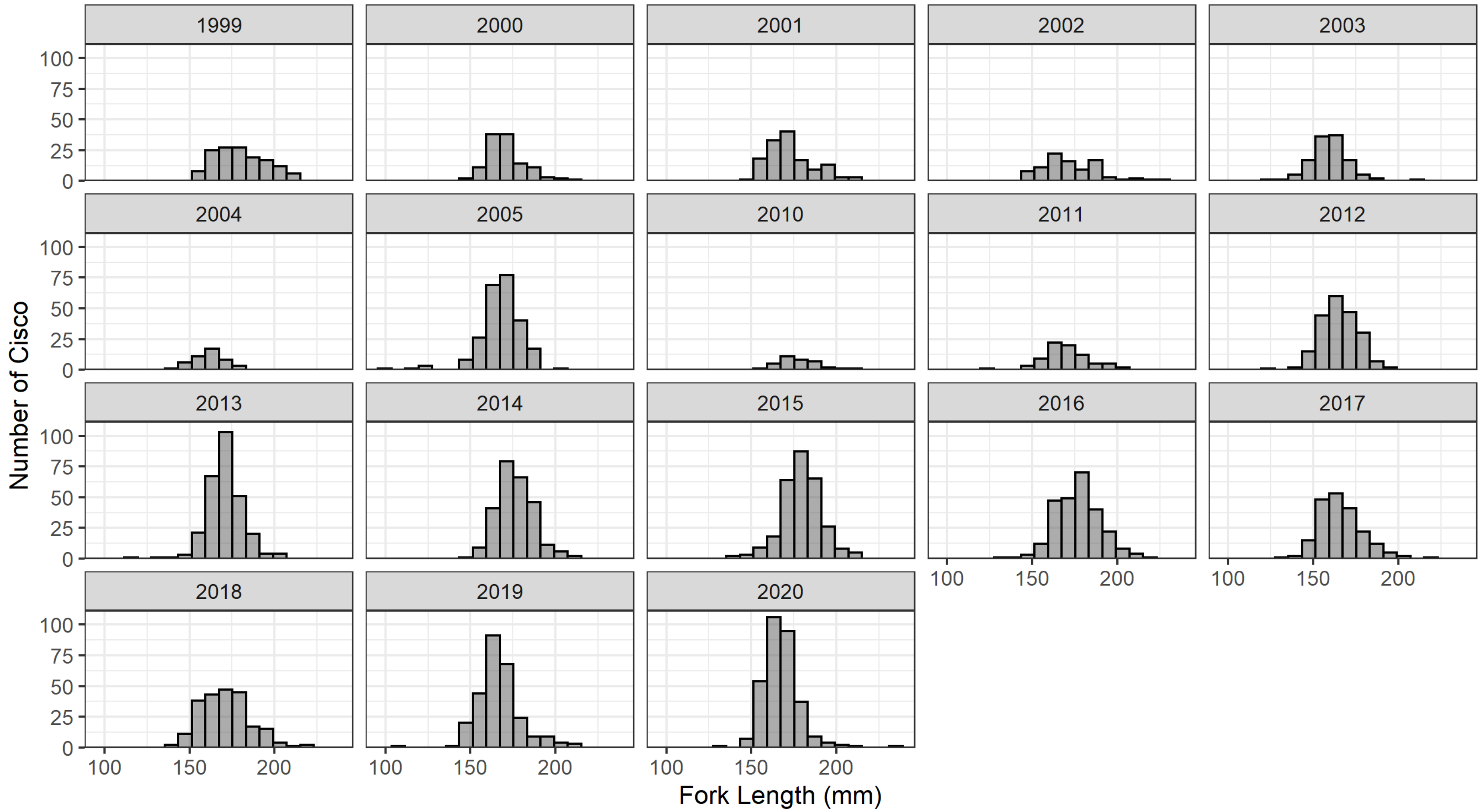


Figure 15. Length-frequency distribution of Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020.

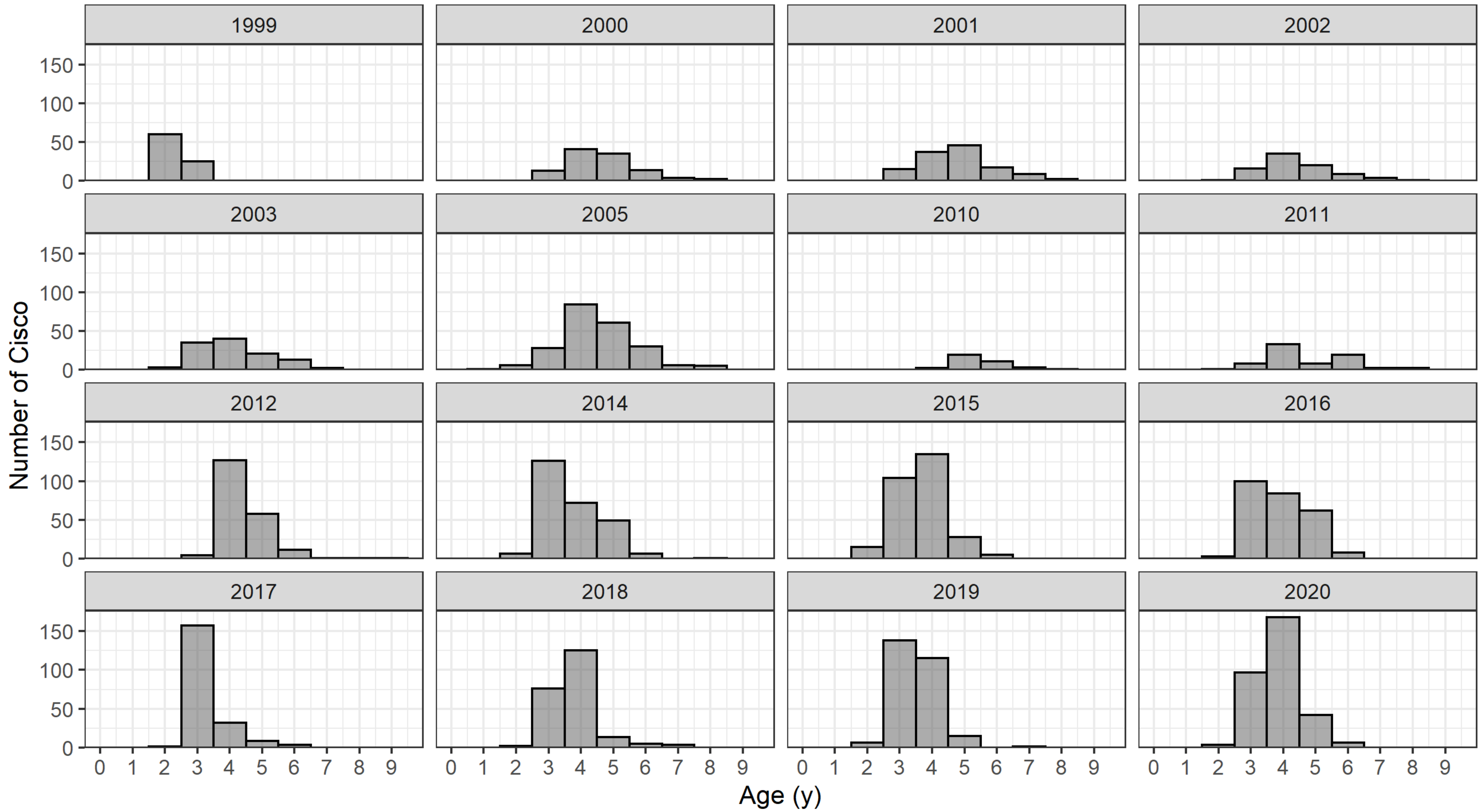


Figure 16. Age-frequency distribution of Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020.

3.4.3 Reproduction and Sex Ratio

The majority of Cisco (>99%) sampled from the Yellowknife River between 1999–2020 were sexually mature confirming that fish were collected from the fall spawning migration (Table A3.1). The youngest mature individuals for both sexes were 2 years. Male gonad weights ranged from 0.061–7.542 g and GSI ranged from 0.09–10.67% (Figure 17). Gonad weights for female Cisco ranged from 0.161–18.880 g and GSI ranged from 0.38–18.16%. Median GSI for male fish ranged from 0.99% to 1.27%, while median GSI for female fish was considerably greater and ranged from 9.24% (2018) to 11.96% (2019) (Figure 17). Significant differences in relative gonad weight were observed among years for both male and female Cisco (Table A3.4, Figure 18), with relative gonad weight of female fish in 2018 notably lower than other years. Neither male nor female Cisco exhibited a trend in gonad weight or GSI over time (Table 10), suggesting differences among years may reflect natural variability in this population.

The GSI of Cisco varied between sites for male and female fish (Table A3.5). For fish captured using dip nets, relative gonad weights of fish sampled from Bluefish were 18% greater for male fish and 12% greater for female fish when compared to Tartan Rapids, suggesting Cisco continued to mature during their upstream migration. Direct comparisons could not be made between sites for gill nets, or between gear types within each site due, to the limited sample sizes available across years for these comparisons.

The male:female ratio of Cisco captured by dip nets at Tartan Rapids varied considerably among years, ranging from 0.2 (2010) to 3.6 (2012); however, the ratio for the total sample 2010–2020 was 1.0 (Table 11).

Table 11. Number of male, female, and total and the overall sex ratio of Cisco captured with dip nets by the fishery-independent survey at Tartan Rapids, Yellowknife River, Northwest Territories, 2010–2020.

Year	Male	Female	Total	Sex Ratio (males:female)
2010	6	30	36	0.2
2011	51	24	75	2.1
2012	162	45	207	3.6
2013	143	131	274	1.1
2014	138	123	261	1.1
2015	129	158	287	0.8
2016	117	141	258	0.8
2017	152	50	202	3.0
2018	115	110	225	1.0
2019	97	178	275	0.5
2020	125	192	317	0.7
Total	1,235	1,182	2,417	1.0

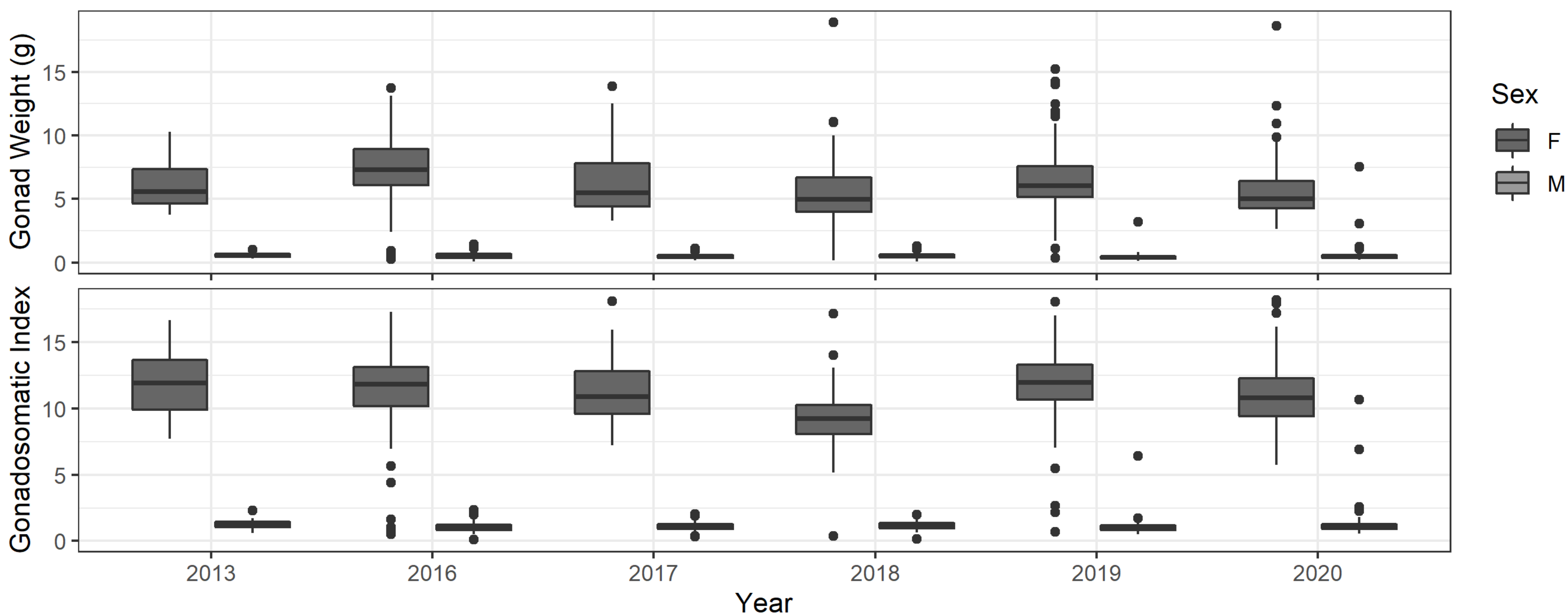


Figure 17. Gonad weight and gonadosomatic index for female (F) and male (M) Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2013 and 2016–2020.

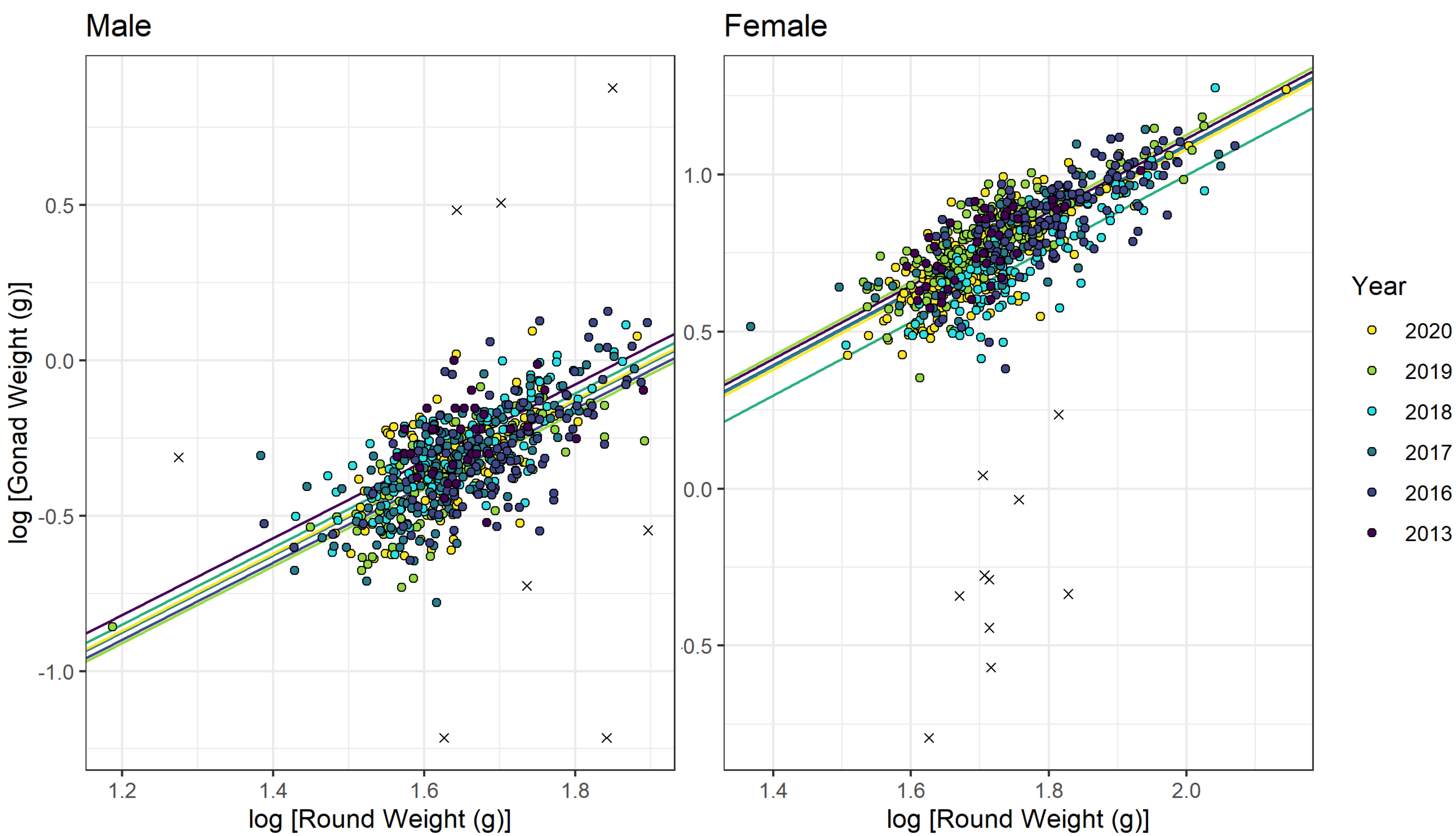


Figure 18. Comparison of gonad weight relative to round weight for male and female Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2013 and 2016–2020. Note: outliers indicated by the symbol 'x' (not included in analysis).

3.4.4 Energy Storage

Condition factor of Cisco sampled using dip nets from the Tartan Rapids, 1999–2020, ranged between 0.50 and 2.20, with the majority between 0.9 and 1.2 (Figure 19). Condition factor of male Cisco ranged from 0.69 to 2.20 with the majority between 0.85 and 1.10, while female Cisco ranged from 0.57 to 1.77 with the majority between 0.9 and 1.15. Significant differences were observed in condition factor among years for male and female Cisco (Table A3.6, Figure 20), with median values for males ranging from 0.91 (2010) to 1.00 (2016) and 0.96 (2011) to 1.07 (2019) for females. When sexes were considered separately (2010–2020), upward trends in condition factor were detected for both males and females, with average increases of 0.01 per year for both sexes over that period (Table 10). However, when sexes were pooled and the dataset examined from 1999 to 2020, Cisco did not exhibit an increasing trend over time.

Liver weight of male Cisco ranged from 0.084 g to 1.378 g and LSI ranged from 0.28% to 2.36%, while liver weight of female fish ranged from 0.089 g to 1.654 g, with LSI ranging from 0.17% to 2.17% (Figure 21). Median LSI for male fish ranged from 0.63% to 0.69%, while median LSI for females were greater and ranged from 0.85% to 1.23% (Figure 21). Significant differences in LSI were observed among years for both male and female Cisco (Table A3.7, Figure 22), with relative liver weight of male and female fish notably greater in 2018.

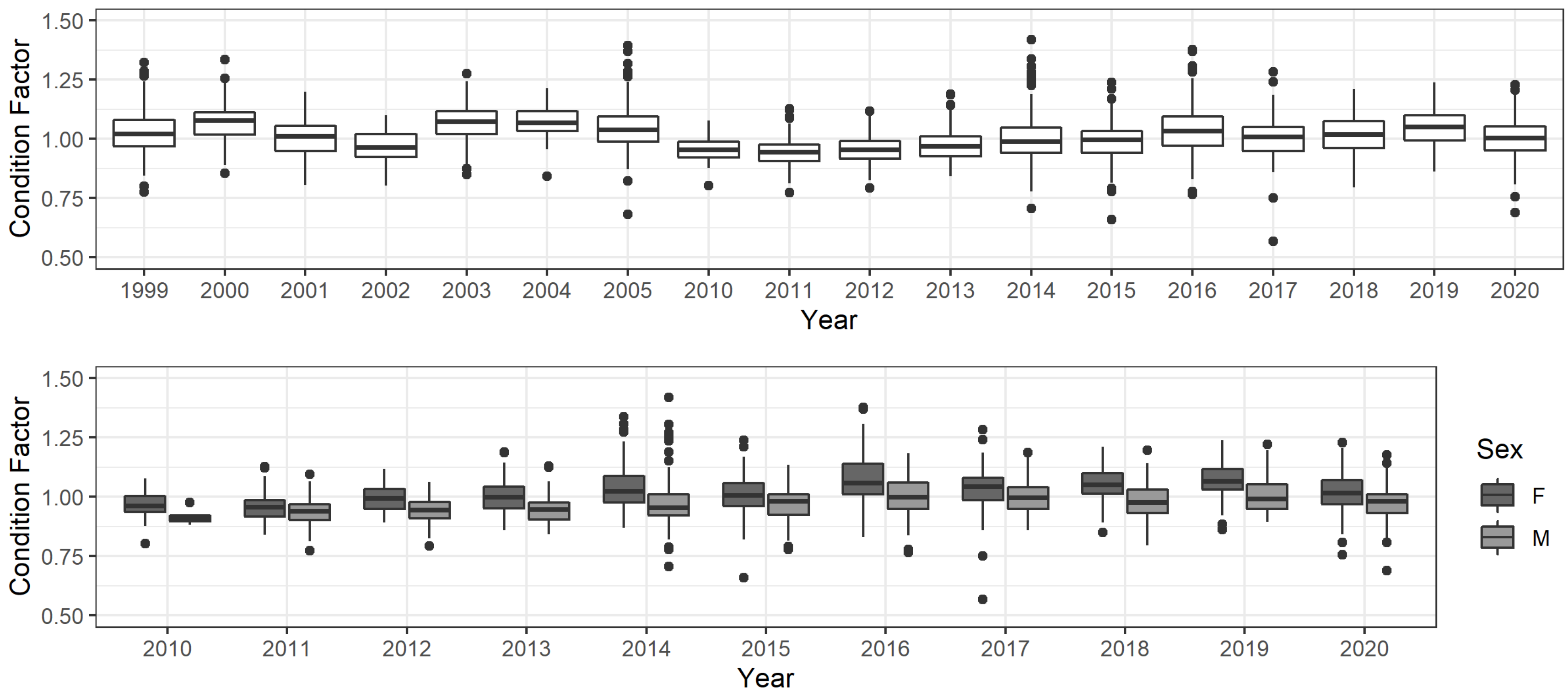


Figure 19. Condition factor box plots (median, quartiles, outliers (● values ≥1.5 x IQR) for the total sample (top) and female (F) and male (M) (bottom) Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020. Note: Value of 2.20 for a male fish in 2017 was omitted to improve data visualization.

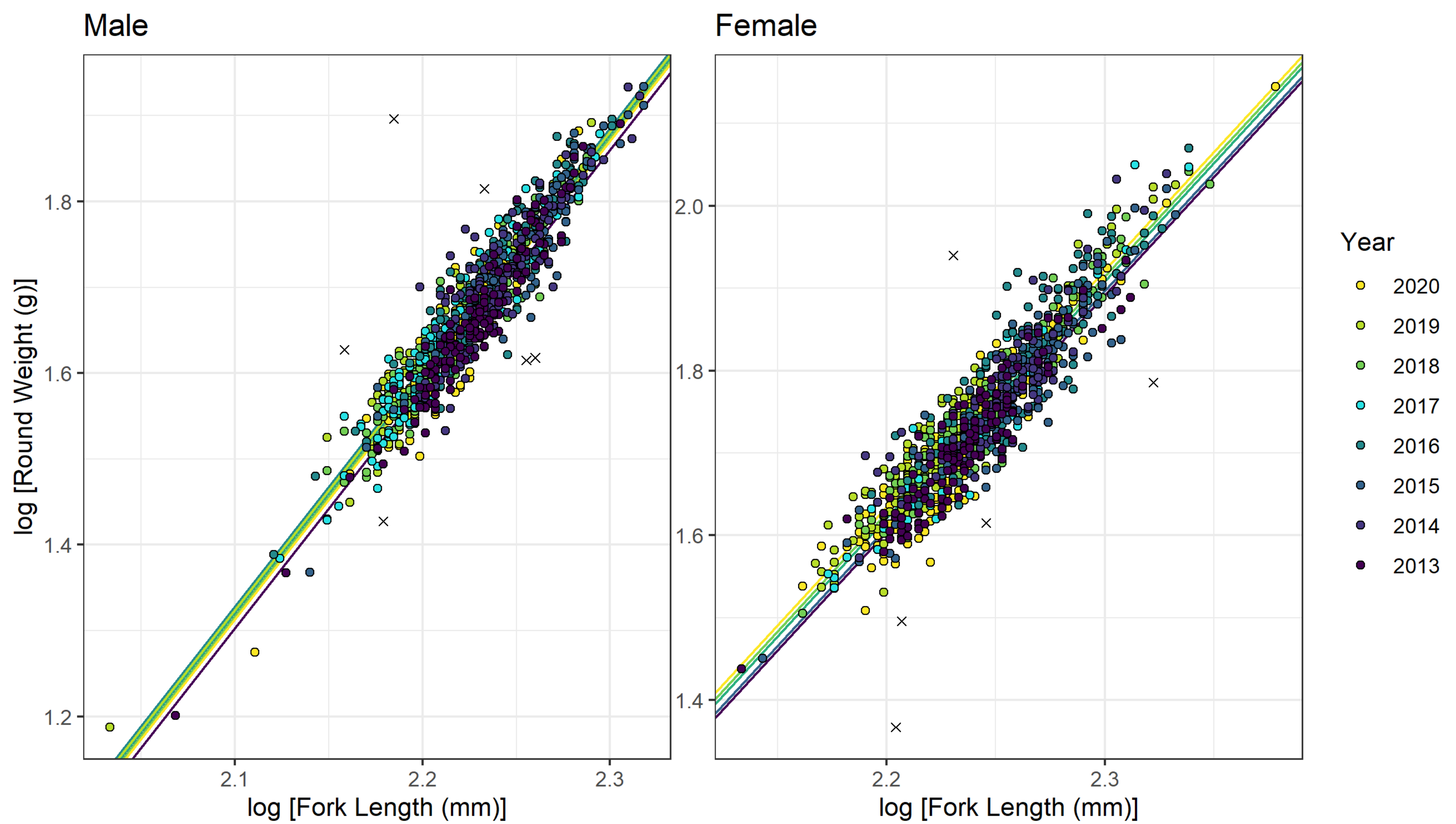


Figure 20. Length-weight relationship for male and female Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2013–2020. Note: outliers indicated by the symbol ‘x’ (not included in analysis).

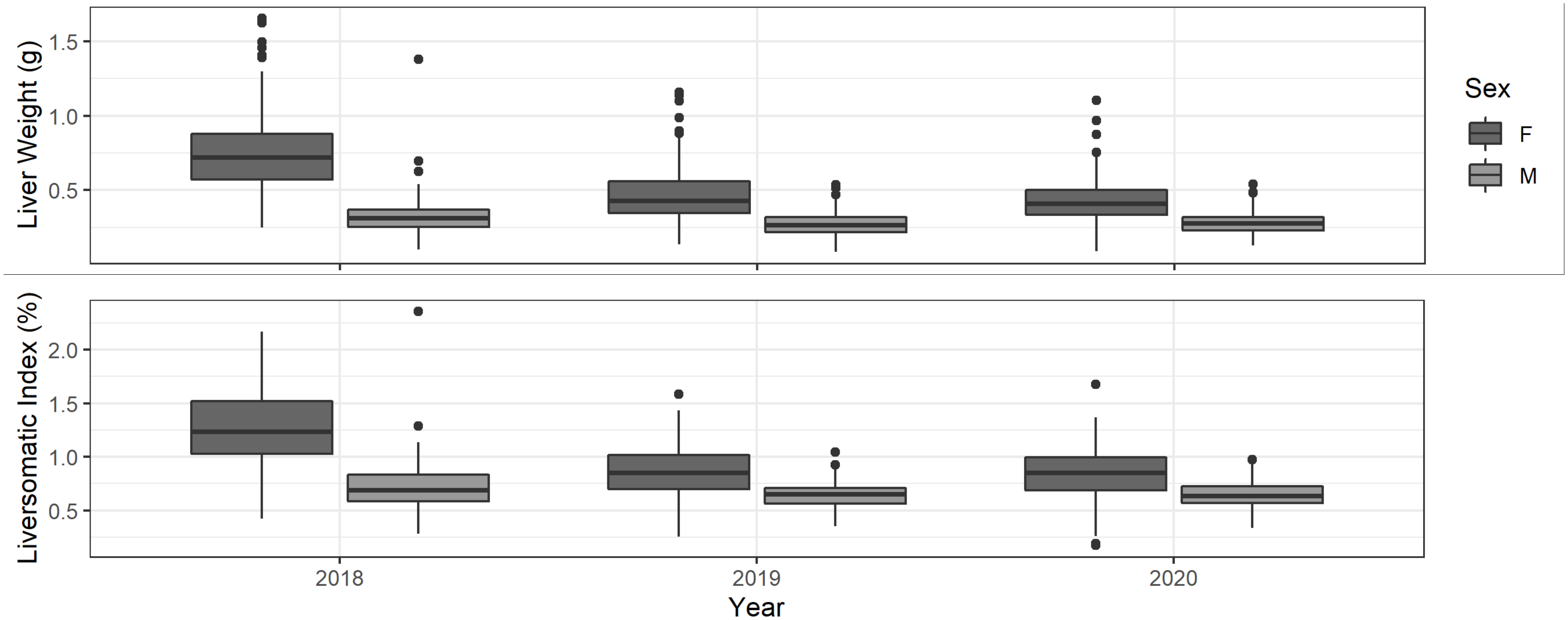


Figure 21. Liver weight and liversomatic index for female (F) and male (M) Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2018–2020.

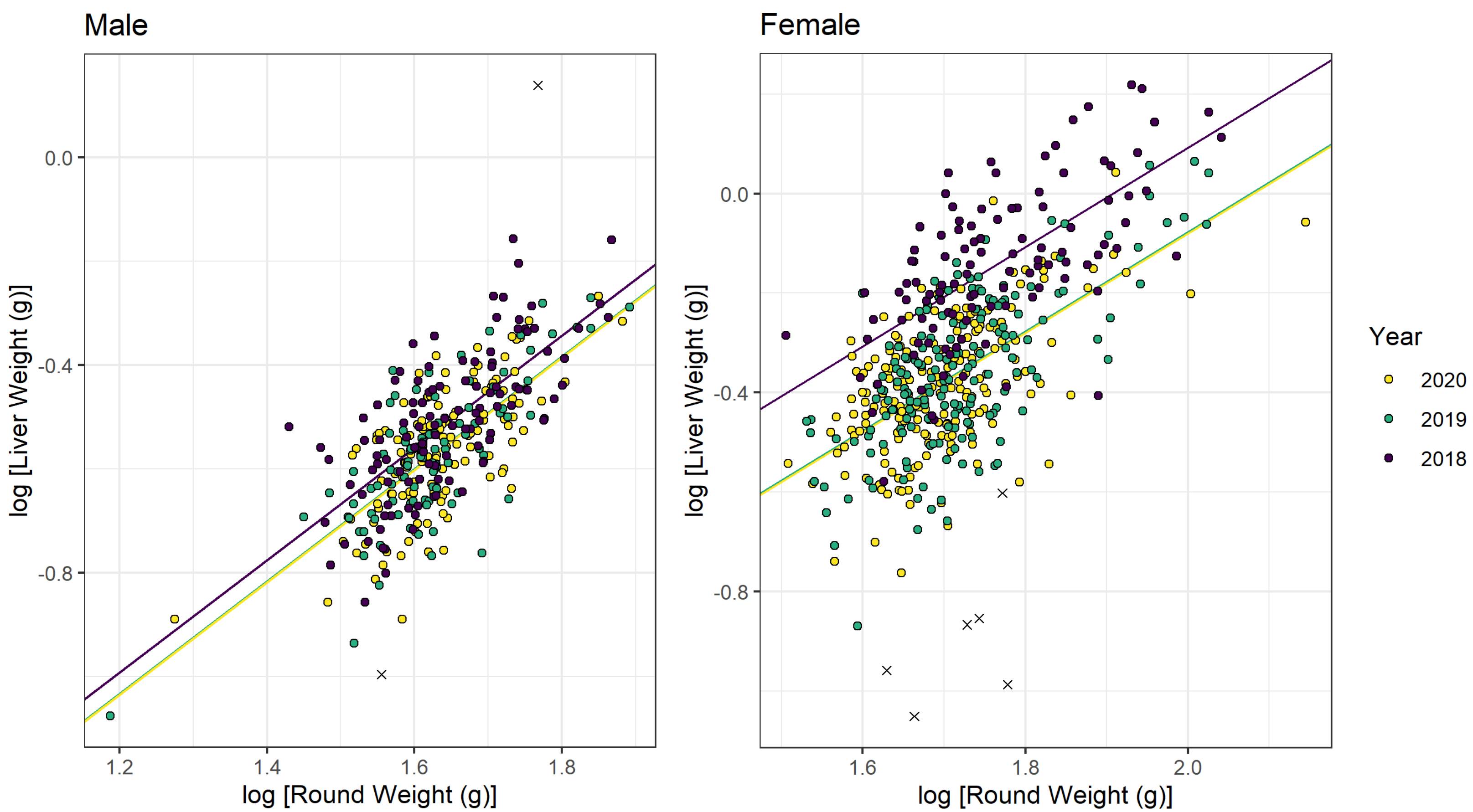


Figure 22. Comparison of liver weight relative to round weight for male and female Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 2018–2020. Note: outliers indicated by the symbol 'x' (not included in analysis).

3.4.5 Growth

Patterns in growth were described using length-weight relationships and the von Bertalanffy growth function of Cisco captured from Tartan Rapids using dip nets.

Length-Weight Relationship

The length-weight relationship of Cisco was estimated using the equation:

$$W = 0.0117L^{2.9483}$$

Estimates and error for this model are provided in Table 12. Growth was generally similar among years, with the lowest rate of growth observed in 2003 and the highest in 2001 (Table 13). No trends were observed in length-weight relationships over time (tau = -0.085, slope = -0.003, *P* = 0.649) and growth was similar between male and female Cisco (*P* = 0.241).

Von Bertalanffy Growth Model

Length-at-age for Cisco was described using the von Bertalanffy growth function:

$$L_t = 197\left[1 - e^{-0.21(t+5.812)}\right]$$

Estimates and error for this model are provided in Table 14. Asymptotic size for Cisco was estimated at 197 mm with an annual growth rate of 41 mm per year (Figure 23), while length-at-age ranged from 159 mm at 2 y to 188 mm at 9 y. Separate growth functions were fit to 10 of the 16 years length and age data were available (Table 15, Figure 24); however, convergence could not be obtained for the remaining years (i.e., 1999, 2002, 2003, 2014, 2018 and 2020). Von Bertalanffy growth parameters varied among years, with L_∞ ranging from 181 mm in 2005 to 212 mm in 2017 and K ranging from 0.201 in 2000 to 1.189 in 2010; however, no trends were detected over time for either parameter (tau = 0.311, slope = 0.500, *P* = 0.243 and tau = 0.022, slope = <0.001, *P* = 1.000, respectively). The growth coefficient for 2010 was dissimilar from the other years examined and should be interpreted with caution given the small sample size (n = 36) and a lack of 2 and 3 year old Cisco, which may have inflated the growth coefficient for this model.

Table 12. Estimates and associated error for length-weight equation for Cisco from Tartan Rapids, Yellowknife River, Northwest Territories.

Parameters	Estimate	Standard Error	95% LCI	95% UCI
Intercept	-4.4508[a]	0.0532	-4.550	-4.347
Log(Fork length [cm])	2.948	0.0187	2.912	2.985

[a] Estimate prior to back transformation

LCI = lower confidence interval; UCI = upper confidence interval.

Table 13. Length-weight relationships for Cisco captured using dip nets from Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020.

Year	Total sample		Male		Female	
	Equation	R^2	Equation	R^2	Equation	R^2
1999	$y=0.0137x^{2.8984}$	0.87	-	-	-	-
2000	$y=0.0095x^{3.0386}$	0.87	-	-	-	-
2001	$y=0.0048x^{3.2572}$	0.92	-	-	-	-
2002	$y=0.0076x^{3.0845}$	0.94	-	-	-	-
2003	$y=0.0200x^{2.7725}$	0.88	-	-	-	-
2004	$y=0.0100x^{3.0253}$	0.89	-	-	-	-
2005	$y=0.0100x^{3.0133}$	0.89	-	-	-	-
2010	$y=0.0065x^{3.1349}$	0.91	$y=0.0534x^{2.3736}$	0.91	$y=0.0089x^{3.0275}$	0.88
2011	$y=0.0111x^{2.942}$	0.92	$y=0.0138x^{2.8603}$	0.90	$y=0.0271x^{2.6423}$	0.86
2012	$y=0.0123x^{2.9093}$	0.91	$y=0.0141x^{2.8563}$	0.93	$y=0.0172x^{2.8061}$	0.90
2013	$y=0.0105x^{2.9709}$	0.89	$y=0.0107x^{2.9579}$	0.92	$y=0.0170x^{2.8138}$	0.86
2014	$y=0.0181x^{2.7914}$	0.77	$y=0.0259x^{2.654}$	0.76	$y=0.0224x^{2.7321}$	0.80
2015	$y=0.0150x^{2.8559}$	0.86	$y=0.0185x^{2.7751}$	0.89	$y=0.0166x^{2.8271}$	0.85
2016	$y=0.0089x^{3.0521}$	0.86	$y=0.0202x^{2.7524}$	0.88	$y=0.0148x^{2.8857}$	0.79
2017	$y=0.0105x^{2.9833}$	0.91	$y=0.0179x^{2.7902}$	0.90	$y=0.0076x^{3.1077}$	0.91
2018	$y=0.0105x^{2.9874}$	0.91	$y=0.0237x^{2.6859}$	0.89	$y=0.0152x^{2.8720}$	0.92
2019	$y=0.0108x^{2.9906}$	0.90	$y=0.0217x^{2.7228}$	0.90	$y=0.0137x^{2.9126}$	0.90
2020	$y=0.0098x^{3.0058}$	0.85	$y=0.0094x^{3.0137}$	0.84	$y=0.0142x^{2.8812}$	0.86

R^2 = coefficient of determination; y= weight (g); x = fork length (cm); - = no data available.

Table 14. Estimates and associated error for von Bertalanffy growth function for Cisco from Tartan Rapids, Yellowknife River, Northwest Territories.

Parameters	Estimate	Standard Error	95% LCI	95% UCI
L_∞	196.8	7.885	187.2	217.7
K	0.2098	0.0681	0.1042	0.3318
t_0	-5.812	1.875	-10.29	-3.411

L_∞ = Asymptotic size; K= growth coefficient; t_0 length at time 0; LCI = lower confidence interval; UCI = upper confidence interval.

Table 15. *Estimates for von Bertalanffy growth function by year for Cisco from Tartan Rapids, Yellowknife River, Northwest Territories.*

Year	**Parameter**		
	L_∞	K	t_0
2000	192	0.201	-6.180
2001	186	0.389	-2.217
2005	181	0.351	-3.251
2010	184	1.189	2.255
2011	193	0.417	-0.777
2012	184	0.535	0.017
2015	191	0.534	-1.773
2016	199	0.410	-1.643
2017	212	0.331	-1.431
2019	188	0.352	-2.775

L_∞ = Asymptotic size; K= growth coefficient; t_0 length at time 0.

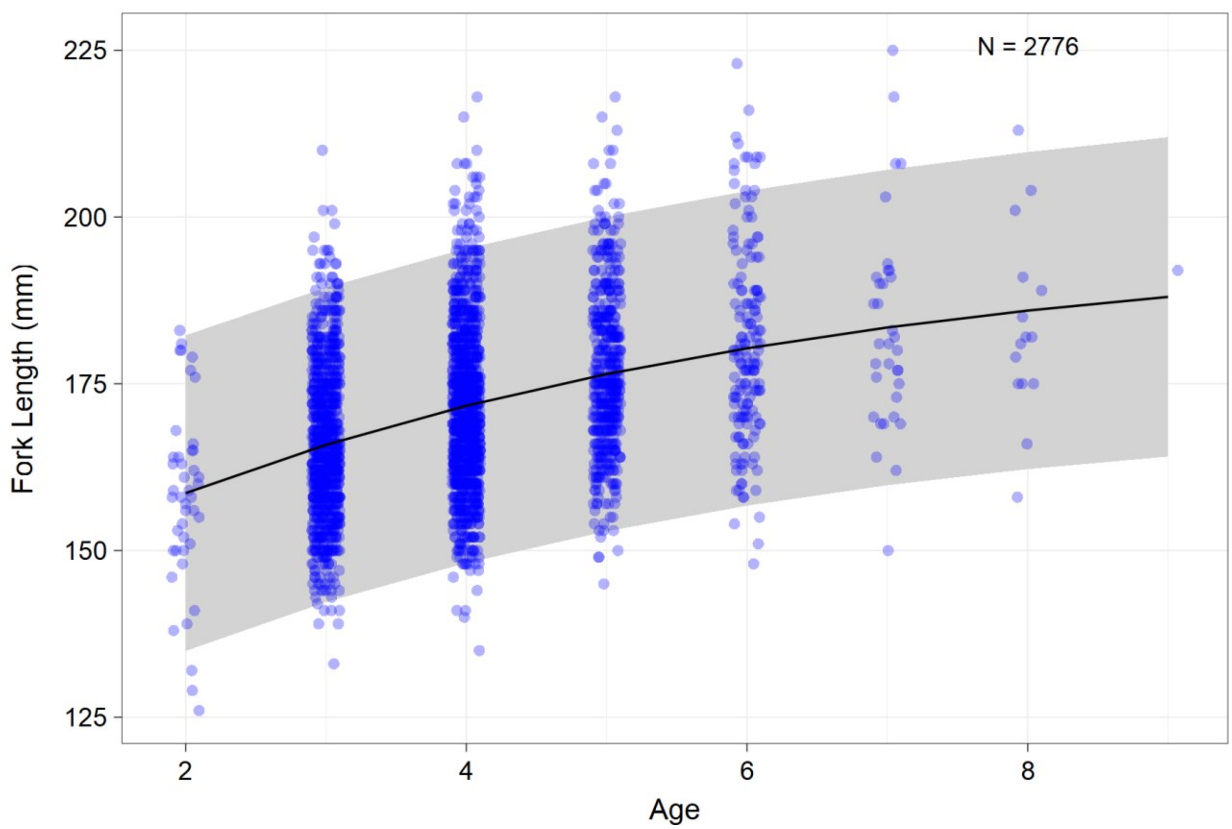


Figure 23. Von Bertalanffy growth curve for Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, 1999–2020. Grey shading indicates the 95% prediction interval of the growth curve.

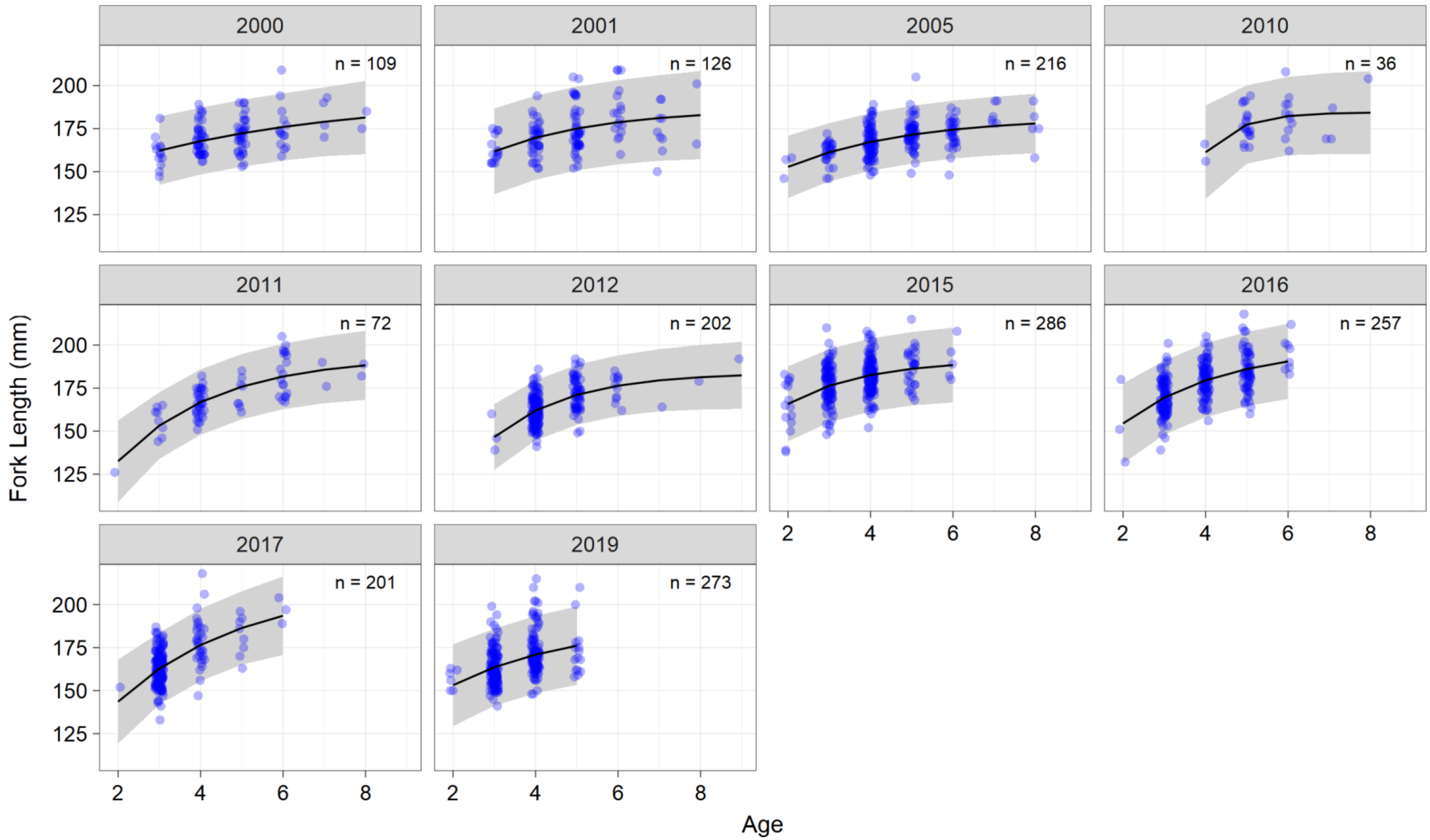


Figure 24. Von Bertalanffy growth curves for Cisco captured using dip nets at Tartan Rapids, Yellowknife River, Northwest Territories, for years where model convergence was obtained, 1999–2020. Grey shading indicates the 95% prediction interval of the growth curve.

4 DISCUSSION

The data collected from the commercial fishery of adfluvial Cisco at Tartan Rapids provides an important benchmark to characterize temporal trends in relative abundance and demographic properties of the spawning stock in the Yellowknife River. While CPUE from the commercial fishery reflected the targeting of Cisco in areas where they were aggregated in large numbers, typically during periods when they were most abundant, the relative abundance information from fisheries-independent (dip net) sampling and snorkel survey data helped inform the results of the commercial fisheries monitoring. The data collected from the various programs are useful to infer the effects of the commercial fishery targeting the population and improve understanding of the biological characteristics of Cisco using the Yellowknife River.

The 15 years of fisheries-dependent CPUE data suggests the relative abundance has been somewhat stable with the exception of 2002, 2012, and 2020 when the quota was reached with less effort, which was indicative of a greater abundance of Cisco spawning in the river in those years (a reminder that CPUE in 2004 is likely not an accurate measure of relative abundance as the duration of the fishery was severely truncated and the quota not met). Interestingly, snorkeling surveys also demonstrated multiple years with consistent results with some that had considerably higher counts. Both sources of data suggest the spawning population can experience important annual fluctuations in abundance at the time of sampling. This variability could potentially be tied to variable recruitment, or alternatively, because these spawning populations are seasonal by nature, variations in abundance within and among years could reflect the distribution of the run timing (i.e., a more condensed run vs. more spread out). Whether years with higher CPUE values accurately reflect the extent of a greater abundance of Cisco is uncertain, especially given the lack of a positive linear relationship between fisheries-dependent CPUE and fish counts from snorkeling. The relatively consistent temporal pattern in CPUE is accompanied by stable trends in the demographic properties indicative of stock status. Specifically, the lack of evident directional changes in length, age, and growth suggests no apparent decline in population status between 1999 and 2020. Quantitative population modelling of harvest, catch-effort, and biological data would allow for further assessment of population status. It is noted that there could be limitations to assessment as the monitoring was solely focused on migrating adults occupying the river while the non-migratory (e.g., juvenile) component of the population presumably remain in Prosperous Lake or Great Slave Lake.

Accounting for other sources of mortality in the stock is useful for management objectives, particularly given that natural mortality rates or removals of Cisco that spawn in the Yellowknife River from other fisheries remain largely unknown. While commercial records from the Yellowknife River have been maintained since the fishery started in 1998, other fisheries targeting this population have not been monitored. Tartan Rapids is a popular and relatively easy to access location in proximity to Yellowknife thereby making it more vulnerable to harvesting pressure (Post et al. 2002; Cott et al. 2015); although, there are no available estimates of total harvest from the sport fishery. Sport fishing limits for harvesting Cisco by dipnet have been implemented throughout the NWT since 2001, with a daily catch and possession limit of 350 Cisco in effect until 2013, when both of these limits were reduced by Variation Order to 175. To date, there have not been any additional sport fishing management measures implemented that are specific to the Yellowknife River. The extent to which Cisco have been fished in the Yellowknife River by Indigenous harvesters historically or in recent years is unclear. Creel surveys designed to collect catch information from sport and Indigenous harvesters would improve future assessment and management of this population. Additionally, there is potential for the population to be caught as bycatch in the Great Slave Lake commercial fishery; however, adfluvial Cisco have rarely been documented in Yellowknife Bay (Vecsei et al 2012).

The lack of association between fishery-dependent gill net and -independent dip net CPUE data at Tartan Rapids (2014-2020) suggests that data from one sampling approach, or both, do not precisely reflect the relative abundance of the spawning run. Reasons for the discrepancy not only include differences in the timing of fishing/sampling but also the considerably lower annual sample sizes from the fishery-independent sampling that likely reduced the accuracy of the data. Additionally, while fishery-independent sampling was standardized by the number of fishers, the number of fishers were not reported from the commercial fishery; consequently, CPUE could not be standardized in a comparable manner reducing comparability between the two approaches. The lack of a robust correlation between fishery-independent (dip net) CPUE and snorkel surveys concomitant with low sample size suggest the available dip net data are not a reliable measure of relative abundance. More dip net sampling over the duration of the spawning run is required to better inform a measure of fisheries-independent CPUE. The capture efficiency of small mesh gillnets was likely impeded by the effects of currents in the eddies where sampling was conducted and is not recommended as a robust means to collect CPUE data for Cisco in the Yellowknife River.

The association between fisheries-dependent CPUE and combined river temperature and discharge in October-November suggest hydrological conditions may be an important determinant in the timing of migratory movements of Cisco in the Yellowknife River. Results suggest that optimal CPUE, as a surrogate of capture efficiency, was associated with temperatures of 10–15 °C and discharge of 35–55 m^3/s. The interpretation of these results should be considered cautiously given that CPUE of the commercial fishery was not standardized to the number of nets/fishers, and that this is a seasonal, patchy, and easily accessible spawning run that is likely to be fished in the most ideal of conditions (e.g., weather and water conditions, abundance of fish.). Additional research is required to understand the extent to which environmental variables, and associated temporal and spatial scales, influence the upstream migration of Cisco and subsequent spawning in this system.

While demographics of the Yellowknife River population appear to have remained relatively stable between 1999 and 2020, adfluvial Cisco are generally smaller and exhibit slower growth, younger age-at-maturity, younger maximum age, and higher mortality, relative to the lacustrine form found in Great Slave Lake (Muir et al. 2011; Vescei et. al 2012; Blackie et al. 2012 ; Muir et al. 2014). The sample sizes attained on an annual basis by recent sampling efforts were generally larger than earlier sample collections, particularly between 2012 and 2020, which allowed for more robust estimation of biological parameters such as length-weight relationships and growth curves. The maximum size of adfluvial Cisco found in the Yellowknife River through this program were slightly larger than had previously been described by Muir et al. 2011 (270 mm standard length and 140 g vs. 192 mm standard length and 89 g), although the range of ages observed was the same (1–9 years). Generally, females were larger and older than males, and although the cumulative sex ratio of the total 1999–2020 sample was equal, ratios were highly variable among years. This variability could be explained in part by the timing of sampling relative to the spawning run, with male Cisco generally reported to arrive on the spawning grounds first (i.e., for lake populations; Scott and Crossman 1973).

While the metrics examined herein did not reveal any declining trends, several uncertainties remain with this population, including its size, total harvest (i.e., including sport and Indigenous fisheries) and other potential threats such as impacts of hydroelectric facilities and climate change, general life history, habitat use, and ecosystem interactions, underscoring the importance of continued monitoring and research. The relative abundance and biological data collected between 1998 and 2020 serve as a valuable benchmark for the ongoing assessment of this fisheries resource. Additional efforts to collect and document Indigenous and local knowledge of this population would benefit future assessment and management approaches. Further engagement and consultations with rights holders, stakeholders, and users of this fishery are needed to evaluate management approaches and develop an updated research and monitoring plan to support the continued sustainability of this population.

5 DATA ACCESS

All biological and catch-effort data collected from this project will be made publicly available on the Government of Canada Open Data Portal https://open.canada.ca/en/open-data.

6 ACKNOWLEDGEMENTS

We gratefully acknowledge the field and program contributions from numerous individuals working with DFO, Golder Associates Ltd., and other organizations over the years. We recognize the commercial fisher and his helpers for their major contributions to the monitoring of this Cisco population through consistently providing their catch records and a portion of their harvest for sampling each year. Fishery-independent and snorkel surveys were conducted under contract by Golder 2013–2020. Monitoring at Bluefish Rapids and upper Prosperous Lake was completed through in-kind support provided by the Northwest Territories Power Corporation (NTPC). NTPC also provided Golder access to the Bluefish sites for sample collection and snorkel surveys used in this study. We would also like to acknowledge field, technical, and program support provided by Deanna Leonard (DFO), Matthew Miller (NTPC), Paul Vescei (Golder), Francois Larouche (Golder), Monica Redmond (Golder), and all others involved in the collection of data. Otoliths were aged by DFO's Arctic and Aquatic Research Division Fish Age Estimation Lab, North/South Consultants Inc., and AAE Tech Services Inc. Support for this report was provided under contract with Golder Associates Ltd., including Barbra Fortin (Project Manager), Christina Campbell, Curtis VanWerkhoven, and Monica Redmond. Funding for field work, biological sampling, and report writing were provided by DFO Fisheries Management. We gratefully acknowledge Pete Cott and Yamin Janjua for their helpful and thorough reviews of this report.

7 REFERENCES

Barrett T.J., Tingley, M.A., Munkittrick, K.R., and Lowell, R.B. 2010. Dealing with heterogeneous regression slopes in analysis of covariance: new methodology applied to environmental effects monitoring fish survey data. Environ. Monit. Assess. 166: 279-291.

Blackie, C.T., Vescei, P., and Cott, P.A. 2012. Contrasting phenotypic variation among river and lake caught Cisco from Great Slave Lake: evidence for dwarf and large morphs. J. Great Lakes Res. 38:798–805.

Burnham K.P., and Anderson D.R. 2003. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd Edition. Springer Science & Business Media.

Cott, P.A., Schein, A. Hannah, B.W., Johnston, T.A., MacDonald, D.D., and Gunn, J.M. 2015. Implications of linear developments on northern fishes. Environ. Rev. 23: 177–190.

Degray, A., 2020. Indigenous risk perceptions and land-use in Yellowknife, NT (Doctoral dissertation, Memorial University of Newfoundland).

Department of Fisheries and Oceans (DFO). 2008. New Emerging Fisheries Policy. Accessed 24 February 2021. https://www.dfo-mpo.gc.ca/reports-rapports/regs/efp-pnp-eng.htm

Dohoo, I.R., Martin, W., Stryhn, H. 2009. Vet. Epi. Res. 2nd Edition. VER Inc., Charlottetown, PE.

Dominion Diamond (Dominion Diamond Ekati Corporation). 2014. Jay Project Developers Assessment Report: Section 9 Fish and Fish Habitat. Submitted to the Mackenzie Valley Land and Water Board. October 2014.

ECCC (Environment and Climate Change Canada). 2021a. Extracted from the Environment and Climate Change Canada Historical Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html) on 10 February 2021.

ECCC (Environment and Climate Change Canada). 2021b. Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 10 February 2021.

Gallagher, C.P., Wastle, R.J., and Howland, K.L. 2021. Evaluating otolith preparation methods for anadromous Arctic Char: establishing an age estimation protocol and comparing historical with contemporary data. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/023. iv + 29 p.

Gallucci, V.F. and T.J. Quinn. 1979. Reparameterizing, fitting, and testing a simple growth model. Transactions of the American Fisheries Society 108: 14–25.

Golder Associates Ltd.. 2013. 2012 Bluefish Flow Monitoring Program Annual Report. Prepared by Golder Associates Ltd. for the Northwest Territories Power Corporation (NTPC). 31 March 2013.

Golder (Golder Associates Ltd.). 2016. Bluefish Lake Hydroelectric Plant 2015 Fisheries and Flow Monitoring Report. Prepared by Golder Associates Ltd. for the Northwest Territories Power Corporation. May 2016.

Golder. 2017. Bluefish Hydroelectric Plant 2016 Fisheries and Flow Monitoring Report. Prepared by Golder Associates Ltd. for the Northwest Territories Power Corporation. April 2017.

Golder. 2018. Bluefish Hydroelectric Plant 2017 Fisheries and Flow Monitoring Report. Prepared by Golder Associates Ltd. for the Northwest Territories Power Corporation. April 2018.

Golder. 2019. Bluefish Hydroelectric Plant 2018 Fisheries and Flow Monitoring Report. Prepared by Golder Associates Ltd. for the Northwest Territories Power Corporation. May 2019.

MacKenzie, C.J.A., Fortin, B.L., and Stevens C.E. 2022. Summary of Ecological Information Relevant to Great Slave Lake Fisheries. Can. Manuscr. Rep. Fish. Aquat. Sci. 3214: vii +63 p

Muir, A. M., Vecsei, P., and Reist, J.D. 2011. A field guide to the taxonomy of Ciscoes in Great Slave Lake, Northwest Territories, Canada. Great Lakes Fish. Comm. Misc. Publ. 2011–02. 46 pp.

Muir, A. M., Vecsei, P., Power, M., Krueger, C.C., and Reist, J.D. 2014. Morphology and life history of the Great Slave Lake Ciscoes (Salmoniformes: Coregonidae). Ecol. Freshw. Fish 23:453–469.

Post, J.R., Sullivan, M., Cox, S., Lester, N.P., Walters, C.J., Parkinson, E.A., Paul, A.J., Jackson, L., and Shuter, B.J. 2002. Canada's recreational fisheries: the invisible collapse? Fisheries, 27: 6–17.

Sakamoto, Y., Ishiguro, M., and Kitagawa G. 1986. Akaike Information Criterion Statistics. D. Reidel Publishing Company.

Schnute, J., and D. Fournier. 1980. A new approach to length-frequency analysis: Growth structure. Canadian Journal of Fisheries and Aquatic Sciences 37:1337–1351.

Scott, W.B., and Crossman, E.J. 1973. The Freshwater Fishes of Canada. Fish. Res. Board Can. Galt House Publications Ltd, Oakville, Ontario. 966 p.

Turgeon, J., Reid, S.M., Bourret, A., Pratt, T.C., Reist, J.D., Muir, A.M., and Howland, K.L. 2016. Morphological and genetic variation in Cisco (Coregonus artedi) and Shortjaw Cisco (C. zenithicus): multiple origins of Shortjaw Cisco in inland lakes require a lake-specific conservation approach. Conserv. Genet. 17:45–56.

Vecsei, P., Blackie, C.T., Muir, A.M., Machtans, H.M., and Reist, J.D. 2012. A preliminary assessment of Cisco (Coregonus spp.) diversity in Yellowknife Bay, Great Slave Lake, Northwest Territories. Adv. in Limnol. 63:299–322.

8 APPENDICES

8.1 APPENDIX 1: ANNUAL MEAN DAILY FLOWS FOR THE YELLOWKNIFE RIVER AND NEARBY RIVERS.

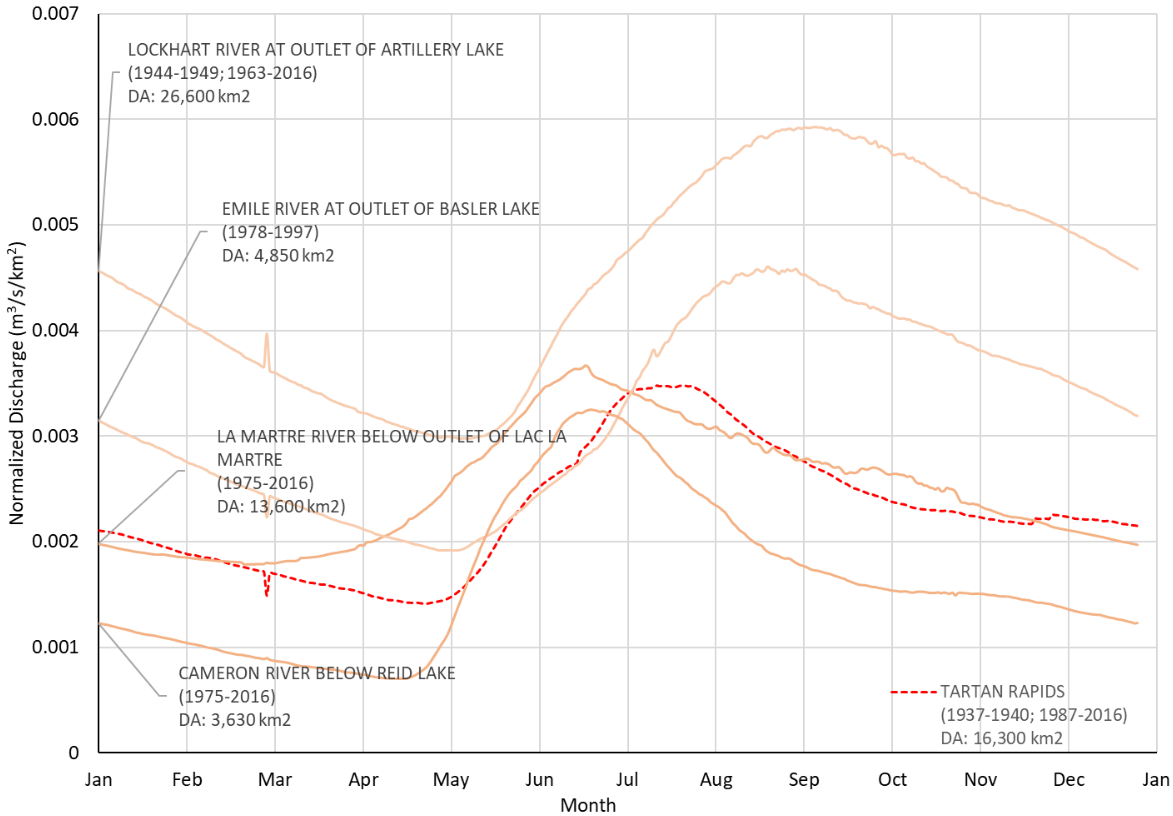


Figure A1. Historical Data from Water Survey of Canada Stations summarized as (normalized) mean daily flows for the Yellowknife River and nearby rivers of similar size (ECCC, unpublished).

8.2 APPENDIX 2: FISH MATURITY NUMERIC CODES: FISHERIES AND OCEANS CANADA STANDARDS FOR ITEROPAROUS FISHES IN THE NORTH

Sex:

Male = 1;

Female =2.

Maturity Flow Chart:

Immature → Maturing/Mature → Ripe (spawning) → Spent → Resting (>1 or more years).

Note 1: Once energy reserves are re-accumulated then individuals return to the Maturation phase and spawn again. Also, resting periods are population and sex specific, and may not occur in some; and, duration of resting period appears to be flexible in most populations and dependent primarily upon the accumulation rate of food/energy.

Note 2: Descriptions in the table are generalisations and variation or departure from these is possible. Also, all criteria within a category may not be present in a particular individual.

Note 3: These qualitative descriptions and assignments to categories on a continuum should be backed up where possible by gonad weight, which together with body weight (round) can be used to calculate gonadosomatic index.

Maturity Codes (use numeric codes on data sheets with notes as/if needed):

Maturity State	Female	Male
Immature (virgin)	1. - ovaries granular in texture - hard and triangular in shape - ovaries up to full length of body cavity - membrane full - eggs distinguishable	6. - testes long and thin - tubular and scalloped shape - up to full length of body cavity - putty-like firmness
Mature	2. - current year spawner - ovary fills body cavity - eggs near full size but not loose (i.e., membrane intact) - eggs not expelled by pressure	7. - current year spawner - testes large and lobate - white to purplish in colour - centres may be fluid filled - milt not expelled by pressure
Ripe	3. - ovaries extended and fill body cavity - eggs full size and transparent - membrane breaking down and eggs expelled by light pressure	8. - testes full size - white and lobate - milt expelled by slight pressure
Spent	4. - spawning complete - ovaries ruptured and flaccid - developing oocytes visible - some eggs retained in body cavity	9. - spawning complete - testes flaccid with some milt - blood vessels obvious - testes violet-pink in colour
Resting	5. - ovary 40-50% of body cavity - membrane thin, loose and semi-transparent - healed from spawning - developing oocytes in various stages with a few atretic large eggs still present - some eggs may be retained in body cavity	10. - testes tubular, less lobate - healed from spawning - no fluid in centre - usually full length of body cavity - mottled and purplish in colour
Unknown (virgin)	0. - can not be sexed - gonads long or short but thin - gonads transparent or translucent	
Unknown (non-virgin)	11. - resting fish - has spawned but gonads regenerated - sexing not possible for some reason	

8.3 APPENDIX 3. DATA COMPARISONS

Table A3.1. Comparisons of Cisco length, weight and age sampled among years sampled through the commercial and fishery independent surveys.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Fork Length[(a)]					
Year	6	0.333	0.055	64.267	<0.001
Survey	1	0.002	0.002	2.251	0.134
Residuals	1807	1.560	0.001		
Total Weight[(a)]					
Year	6	2.623	0.437	48.874	<0.001
Survey	1	0.021	0.021	2.395	0.122
Residuals	1801	16.108	0.009		
Age[(a)]					
Year	6	0.833	0.139	17.60	<0.001
Survey	1	0.141	0.141	17.94	<0.001
Residuals	1811	14.280	0.008		

a) Differences in r^2 with and without the interaction term included in model were less than 2% and were considered practically similar (Barrett et al. 2010). The results of the reduced model are presented.
df = degrees of freedom.

Table A3.2. Comparisons of Cisco length, weight and age sampled among years, sites and gear types.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Fork Length[(a)]					
Year	7	0.472	0.067	77.551	<0.001
Site	1	0.080	0.080	92.062	<0.001
Gear	1	0.002	0.002	2.279	0.131
Residuals	2487	2.162	0.001		
Total Weight[(a)]					
Year	7	3.484	0.498	57.083	<0.001
Site	1	0.601	0.601	67.896	<0.001
Gear	1	0.041	0.041	4.725	0.030
Residuals	2478	21.604	0.009		
Age[(a)]					
Year	6	58.7	9.785	17.202	<0.001
Site	1	0.100	0.090	0.158	0.691
Gear	1	2.300	2.327	4.091	0.043
Residuals	2137	1215.6	0.569		

a) Differences in r^2 with and without the interaction term included in model were less than 2% and were considered practically similar (Barrett et al. 2010). The results of the reduced model are presented.
df = degrees of freedom.

Table A3.3. Comparisons of male and female length, weight and age among years for Cisco captured using dip nets at Tartan Rapids.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Fork Length[(a)]					
Year	7	0.474	0.068	81.79	<0.001
Sex	1	0.130	0.130	156.55	<0.001
Residuals	2480	2.053	0.001		
Total Weight[(a)]					
Year	7	3.48	0.497	64.37	<0.001
Sex	1	2.98	2.980	385.88	<0.001
Residuals	2474	19.10	0.008		
Age[(a)]					
Year	6	0.749	0.125	16.57	<0.001
Sex	1	1.010	1.010	134.06	<0.001
Residuals	2143	16.147	0.008		

a) Differences in r^2 with and without the interaction term included in model were less than 2% and were considered practically similar (Barrett et al. 2010). The results of the reduced model are presented.
df = degrees of freedom.

Table A3.4. Comparisons of male and female relative gonad weight among years for Cisco captured using dip nets at Tartan Rapids.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Male					
Weight	1	7.513	7.513	602.416	<0.001
Year	5	0.375	0.075	6.019	<0.001
Residuals	628	7.832	0.012		
Female[(a)]					
Weight	1	9.496	9.496	1349.85	<0.001
Year	5	1.160	0.232	32.99	<0.001
Residuals	695	4.889	0.007		

a) Differences in r^2 with and without the interaction term included in model were less than 2% and were considered practically similar (Barrett et al. 2010). The results of the reduced model are presented.
df = degrees of freedom.

Table A3.5. Comparisons of male and female relative gonad weight among years and sites for Cisco captured using dip nets.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Male[(a)]					
Weight	1	9.426	9.426	732.11	<0.001
Year	5	0.797	0.159	12.39	<0.001
Site	1	0.296	0.296	22.99	<0.001
Residuals	709	9.128	0.013		
Female[(a)]					
Weight	1	11.188	11.188	1570.41	<0.001
Year	5	1.278	0.256	35.87	<0.001
Site	1	0.104	0.104	14.54	0.001
Residuals	751	5.350	0.007		

a) Differences in r^2 with and without the interaction term included in model were less than 2% and were considered similar (Barrett et al. 2010). The results of the reduced model are presented.
df = degrees of freedom.

Table A3.6. Comparisons of male and female relative weight among years for Cisco captured using dip nets at Tartan Rapids.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Male					
Weight	1	7.744	7.744	8453.938	<0.001
Year	7	0.054	0.008	8.372	<0.001
Residuals	1000	0.916	0.001		
Female					
Weight	1	8.775	8.775	8091.1	<0.001
Year	7	0.135	0.019	17.8	<0.001
Residuals	1061	1.151	0.001		

Note: No significant interactions were observed. The results of the reduced models are presented.
df = degrees of freedom.

Table A3.7. Comparisons of male and female relative liver weight among years for Cisco captured using dip nets at Tartan Rapids.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Male					
Weight	1	3.052	3.052	359.635	<0.001
Year	2	0.128	0.064	7.558	0.001
Residuals	331	2.809	0.009		
Female					
Weight	1	6.098	6.089	460.84	<0.001
Year	2	2.285	1.143	86.35	<0.001
Residuals	465	6.153	0.013		

Note: No significant interactions were observed. The results of the reduced models are presented.
df = degrees of freedom.

Table A3.8. Comparisons of male and female relative liver weight among years and sites for Cisco captured using dip nets.

Comparison	df	Sum of Squares	Mean Sum of Squares	F value	*P*-value
Male					
Weight	1	3.478	3.478	426.195	<0.001
Year	2	0.135	0.067	8.257	<0.001
Site	1	0.003	0.003	0.363	0.547
Residuals	357	2.913	0.008		
Female					
Weight	1	6.187	6.187	466.801	<0.001
Year	2	2.403	1.201	90.635	<0.001
Site	1	0.047	0.047	3.514	0.062
Residuals	482	6.389	0.013		

Note: No significant interactions were observed. The results of the reduced models are presented.
df = degrees of freedom.

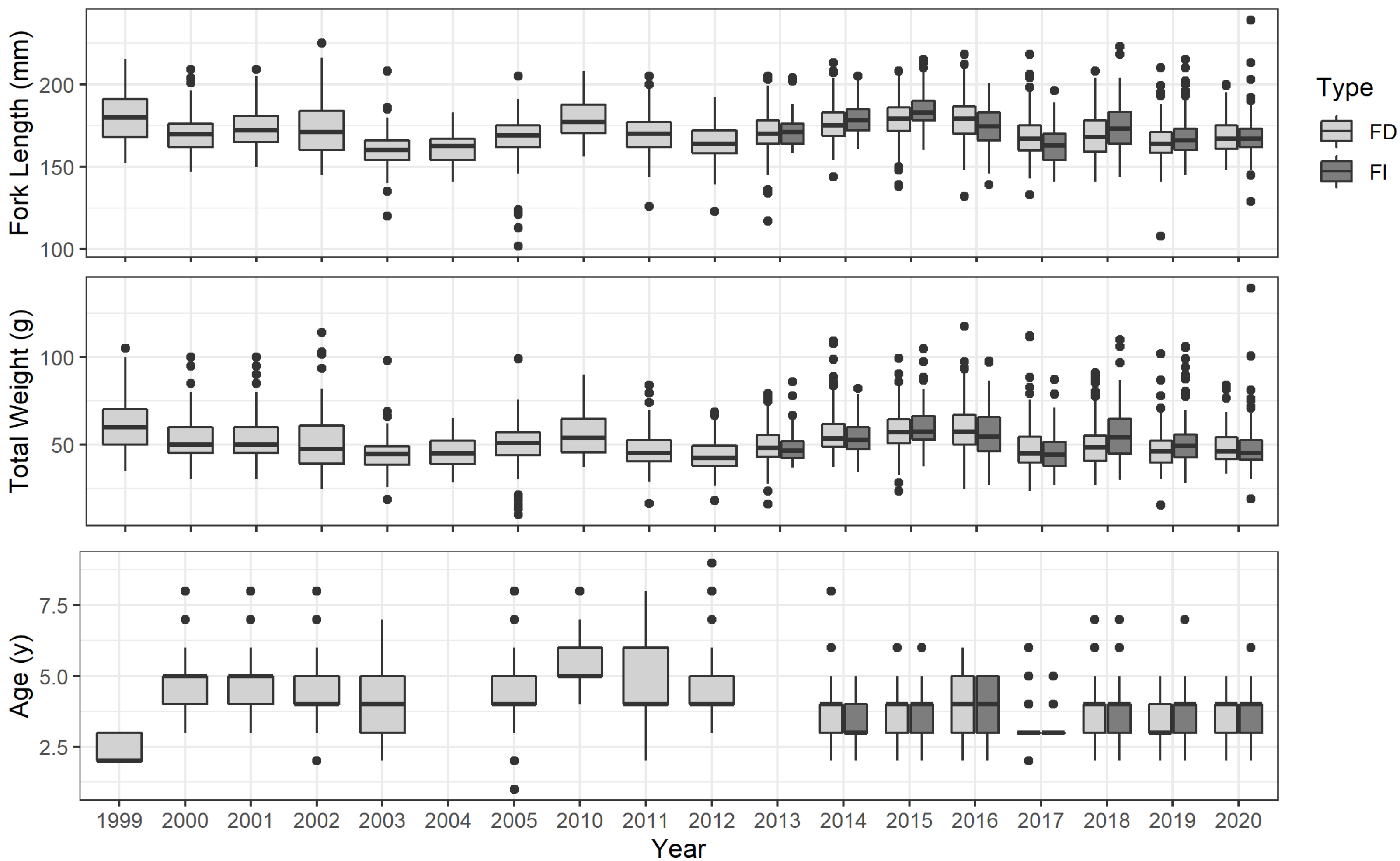
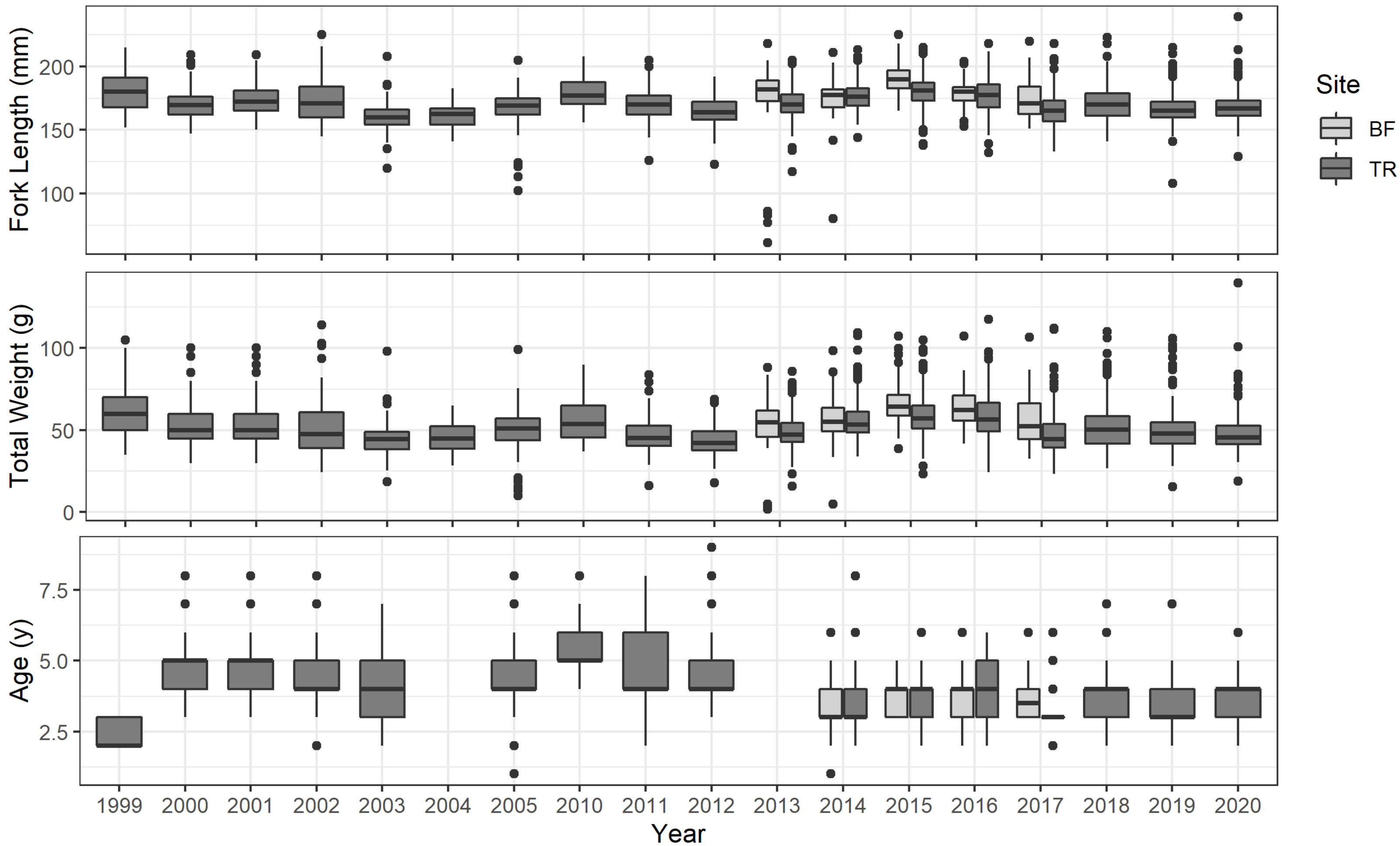
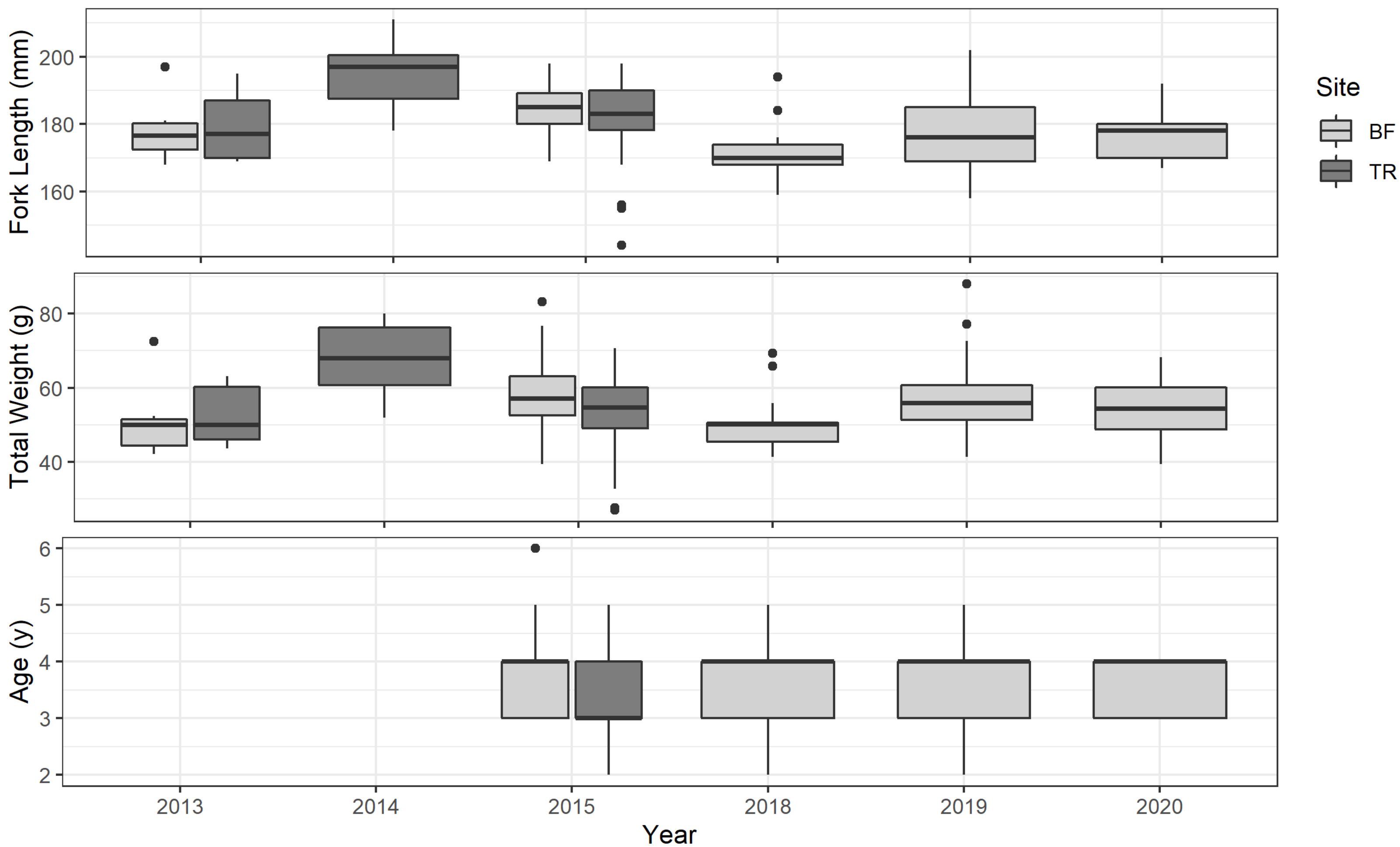


Figure A3.1. Comparison of Cisco fork length, total weight, and age captured from Tartan Rapids, Yellowknife River, Northwest Territories, during the fishery-dependent (FD, commercial) and fishery-independent (FI) sampling, 1999–2020.



BF = Bluefish; TR = Tartan Rapids.

Figure A3.2. Comparison of Cisco fork length, total weight and age captured using dip nets from Tartan Rapids and Bluefish, Yellowknife River, Northwest Territories.



BF = Bluefish; TR = Tartan Rapids.

Figure A3.3. Comparison of Cisco fork length, total weight and age captured using gill nets from Tartan Rapids and Bluefish, Yellowknife River, Northwest Territories.