Appendix 44

Whale Tail 2021 Fish Habitat Offset Monitoring Report

MEADOWBANK COMPLEX

2021 FISH HABITAT OFFSETS MONITORING REPORT

In Accordance with

DFO *Fisheries Act* Authorization 16-HCAA-00370

and

DFO *Fisheries Act* Authorization 20-HCAA-00275

Prepared by:
Agnico Eagle Mines Limited – Meadowbank Complex

March, 2022

EXECUTIVE SUMMARY

In accordance with *Fisheries Act* Authorizations 16-HCAA-00370 and 20-HCAA-00275, Agnico Eagle maintains a Fish Habitat Offsets Monitoring Plan (FHOMP; Version 2, July, 2021 – Agnico Eagle, 2021[1]) for the Whale Tail Site. This Plan was developed to determine whether fish habitat offsetting described in the *Whale Tail Pit - Fish Habitat Offsetting Plan* (C. Portt and Associates, 2018a) and the *Whale Tail Pit Expansion Project Fish Habitat Offsetting Plan* (ERM, 2020) is ultimately constructed and functioning as intended.

From 2021 to 2023, monitoring will be conducted under the pre-offsetting ecological monitoring program of the FHOMP. This program is intended to demonstrate whether terrestrial flooding that was temporarily required for operational purposes will provide suitable habitat for fish long-term. Permanently raised water levels are accepted offsets under both the 2018 and 2020 offsetting plans for the Whale Tail site, and flood zone assessment prior to permanent sill construction is required under conditions of the associated *Fisheries Act* Authorization 20-HCAA-00275.

In 2021, FHOMP assessments included: flood zone water quality data collected through the Core Receiving Environment Monitoring Plan (CREMP), a periphyton growth pilot test using artificial substrate samplers, and small-bodied fish population assessments by shoreline electrofishing. Results of these assessments are presented here in a data report format, with final analysis to be completed following the 2023 monitoring season.

Briefly, 2021 CREMP results indicate suitable water quality for aquatic life within the Whale Tail flood zone, and electrofishing studies identified the presence of small-bodied fish populations in newly created shoreline habitat at rates no lower than reference areas. The periphyton pilot study was successful in demonstrating that seasonal periphyton biomass as represented by chlorophyll-a concentration can be effectively measured using artificial substrate samplers in the Whale Tail flood zone. Several adjustments to sampler design are proposed for the 2022 season to reduce rates of substrate loss.

In addition to flooding and other constructed habitat offsetting features, a portion of offsetting for Whale Tail Pit is provided through a suite of complementary measures (research projects). No physical monitoring is conducted in relation to research projects. However, progress monitoring is conducted to document annual activities, and results are summarized here to determine when criteria for success have been met.

Six research studies are underway or planned as complementary measures for Whale Tail Pit offsetting. Due to delays in 2020 and 2021, largely as a result of the COVID-19 pandemic, some study periods have been extended by 1 or 2 years, as indicated in Table 1 below. In

[1] Version 2 of the FHOMP was developed to include requirements of both Whale Tail site FAAs (16-HCAA-00370 and 20-HCAA-00275) and was submitted to DFO in July, 2021. No comment from DFO has yet been received but Agnico has pro-actively undertaken monitoring and reporting according to this version in 2021 since no monitoring is scheduled under Version 1 until 2026.

2021, Study 4: *Arctic Grayling Occupancy Modelling* was completed and criteria for success were met with publication of a peer-reviewed manuscript (Ellenor et al., 2021; Appendix B).

Table 1. Whale Tail Pit complementary measures (research projects). *Extended 1 -2 years due to COVID or other delays (new dates shown).

Study	Lead Researcher	Study Period
Study 1: Assessment of changes in aquatic productivity and fish populations due to flooding of Whale Tail South and downstream lakes during operations	H. Swanson	2018 – 2023*
Study 2: Assessment of impacts of the Baker Lake wastewater outflow on aquatic systems including fish and fish habitat	H. Swanson	2019 – 2027*
Study 3: Literature review and field validation of northern lake fish habitat preferences	S. Doka	2018 – 2022*
Study 4: Arctic Grayling occupancy modelling (COMPLETE)	H. Swanson	2018 – 2021
Study 5: End pit lake habitat use	TBD	2027 – 2035 (est.)
Study 6: eDNA methods development	J. Stetefeld	2018 - 2023

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1.1 BACKGROUND

In accordance with *Fisheries Act* Authorizations (FAAs) 16-HCAA-00370 and 20-HCAA-00275, Agnico Eagle maintains a Fish Habitat Offsets Monitoring Plan (FHOMP; Version 2, July, 2021 – Agnico Eagle, 2021[2]) for the Whale Tail Site. This Plan was developed to determine whether fish habitat offsetting described in the *Whale Tail Pit - Fish Habitat Offsetting Plan* (C. Portt and Associates, 2018a) and the *Whale Tail Pit Expansion Project Fish Habitat Offsetting Plan* (ERM, 2020) is ultimately constructed and functioning as intended.

This monitoring program is organized to meet the requirements of the FAAs listed above, specifically:

Fisheries Act Authorization 16-HCAA-00370 for the Whale Tail Pit Project:

- Condition 4.3 – Offsetting criteria to assess the implementation and effectiveness of the offsetting measures: All fish habitat offsetting measures shall be completed and functioning according to the following criteria:
    - 4.3.1 – Offsetting measures shall be carried out in accordance with the measures set out in the Proponent's Whale Tail Pit Fish Habitat Offsetting Plan (including the updated Appendix C, dated May 2018), or the most recent version approved by DFO;
    - 4.3.2 – All offsetting features are to be constructed prior to re-flooding of the north basin of Whale Tail Lake in accordance to the schedule outlined in the Whale Tail Pit Fish Habitat Offsetting Plan dated March, 2018 (or most recent approved version);
    - 4.3.3 – The offsetting features (e.g. shoals) have established aquatic biota and are being utilized by fish for one or more of their life history functions.
- Condition 5.1 – the proponent shall conduct monitoring of the implementation of offsetting measures according to the approved timeline and criteria;
    - 5.1.1 – List of timeline(s) and monitoring and reporting criteria:,
        - 5.1.1.4 – the Proponent shall provide an annual Whale Tail Pit Fish Habitat Offset Monitoring Report to DFO (and interested parties)

[2] Version 2 of the FHOMP was developed to include requirements of both Whale Tail site FAAs (16-HCAA-00370 and 20-HCAA-00275) and was submitted to DFO in July, 2021. No comment from DFO has yet been received but Agnico has pro-actively undertaken monitoring and reporting according to this version in 2021 since under Version 1 of the FHOMP (Agnico Eagle, 2018a), no field monitoring was scheduled until 2026.

following the construction of the offsetting habitat by March 31. The proponent is required to provide the report until DFO indicates this requirement has been met.

- 5.1.1.5 – As part of the annual report, the Proponent shall include, but not limited to:
    - A digital photographic record with GPS coordinates of pre-construction, during construction, and post-construction conditions shall be compiled using the same vantage points and direction to show that the approved works have been completed in accordance with the offsetting plan;
    - A summary of field observations for each respective year as well as the as-built survey;
    - A detailed analysis report summarizing the effectiveness of the offsetting measures.

Fisheries Act Authorization 20-HCAA-00275 for the Whale Tail Pit Expansion Project:

- Condition 4.3 – Offsetting criteria to assess the implementation and effectiveness of the offsetting measures: All fish habitat offsetting measures shall be completed and functioning according to the criteria below;
    - 4.3.1 - Offsetting measures shall be carried out in accordance with the measures set out in the Proponent's offsetting plan dated June 5 2020 in the Whale Tail Pit Expansion Project - Information Requirements in Support of the Application for Authorization Under Paragraph 35(2)(b) of the Fisheries Act prepared by ERM Consultants Canada Ltd and Appendix H – Offsetting Design;
    - 4.3.2 - Where Proponent did not provide the detailed engineering plans, offsetting measures shall also be carried out in accordance with the measures as agreed upon after consultation with DFO and other interested parties as per section 4.8.1;
    - 4.3.3 - The Proponent shall provide DFO with sufficient information for DFO to determine if flooding of south portion of Whale Tail Lake area as a result of the Whale Tail Dike (PATH No.: 16-HCAA-00370) provides suitable habitat and enhances productivity of target species as identified through consultation with local communities prior to commencement of consultation on final design of offsetting sill. A report shall be presented to DFO as outlined in section 5.3.1 of this Authorization.

- Condition 5.1 - Schedule and criteria: The Proponent shall conduct monitoring of the implementation of offsetting measures according to the timeline and criteria below [or according to the timeline and criteria in the offsetting plan approved by DFO, referred to in section 4.2 and attached to this authorization and which are the following:
  - 5.1.1 List of timeline(s) and monitoring and reporting criteria:
    - 5.1.1.1 The Proponent shall monitor the geotechnical aspect of the proposed offsetting sill to establish its efficacy to maintain water levels as predicted and examine erosion or slumping twice a year over a 10-year period following the construction of the offsetting sill in 2026.
    - 5.1.1.2 The Proponent shall monitor both biological (fish use, health and biological traits) and ecological (water quality, periphyton productivity) properties of the offsetting habitat expanding on required monitoring in the Fisheries Act Authorization for the Approved Project (PATH No.: 16-HCAA-00370). The proponent shall conduct the biological monitoring programs every year from the date of issuance of the Authorization to the construction of the offsetting sill to show compliance with criteria 4.3.3 and in years 1, 3, 5 and 10 following the construction of the offsetting habitat to establish efficacy of the offsetting measures to provide suitable habitat and enhance productivity of target species.
- Condition 5.2 - List of reports to be provided to DFO: The Proponent shall report to DFO on whether the offsetting measures were conducted according to the conditions of this authorization by providing the following:
  - 5.2.1 The Proponent shall provide a Whale Tail Expansion Fish Habitat Offset Monitoring Report to DFO including geotechnical and biological and ecological monitoring as per section 5.1.1. The Proponent is required to provide the Report by March 31 of 2027 and update annually for 10 years or until DFO indicates requirements of this Authorization have been met
  - 5.2.2 As part of the annual report the Proponent shall include, but is not limited to:
    - 5.2.2.1 a digital photographic record with GPS coordinates of pre-construction, during construction and post construction conditions shall be compiled using the same vantage points and direction to show that the approved works have been completed in accordance with the offsetting plan, and as-built plans and engineering diagrams;
    - 5.2.2.2 a summary of field observations for each respective year; and,

        - 5.2.2.3 a detailed analysis report summarizing the effectiveness of the offsetting measures including the final engineering designs, and maps from flooding models.

    - 5.2.3 The Proponent shall provide a summary report of all Whale Tail Expansion Fish Habitat Offset Monitoring Reports described in section 5.2.1 before March 31, 2036 to DFO (and interested parties) which shall analyse results from the offsetting measures of the Whale Tail Expansion Project following the construction of the offsetting habitat. DFO reserves the right to request additional Summary Report if annual reporting were to continue until requirement has been met.

- Condition 5.3 Other monitoring and reporting conditions for offsetting:

    - 5.3.1 The Proponent shall provide a detailed Impact Analysis of Fish Habitat from Flooding by March 31 2024. The content of this report shall be discussed and approved by DFO (and interested parties) and will be used to establish if the proposed offsetting measures are likely to provide suitable habitat and enhance productivity of target species.

Further, in accordance with monitoring recommendations in DFO guidance documents (e.g. Smokoroski et al., 2015), two types of monitoring are specified:

1. "Compliance" monitoring assesses the physical structure and stability of offsetting features to verify that they were constructed as designed.

2. "Effectiveness" monitoring of biological and ecological endpoints (water quality, periphyton growth, fish use) to assess whether offsetting features are functioning effectively as fish habitat.

1.2 OBJECTIVES

The majority of habitat gains for Whale Tail Site offsetting are planned to be achieved through habitat creation and enhancement efforts. To ensure that offsets are functioning as effective fish habitat, assessment of the structure, stability, and successful utilization of these features by fish are the primary goals of the monitoring program for habitat enhancement/creation offsets.

The overall objectives of this report are:

a. To describe compliance and effectiveness monitoring methods for assessments conducted in the preceding year according to the FHOMP and describe any deviations from the FHOMP.
b. To present the results of data analyses conducted according to the FHOMP.

c. Using those results, to determine whether defined criteria for success have been met.

In addition to the constructed habitat offsetting features to be monitored through this plan, a portion of offsetting for Whale Tail Pit (FAA 16-HCAA-00370) will be provided through a suite of complementary measures (research projects). Full progress reporting is completed for these programs under separate cover and provided to DFO by May 30 annually, according to conditions of the FAA. Study plans and success criteria for the complementary measures are described in the *Whale Tail Pit - Fish Habitat Offsetting Plan* – Appendix C (May 2018) and referred to minimally here. However, this report does include a summary of research study progress, along with annual activities of the oversight body (Meadowbank Fisheries Research Advisory Group; MFRAG) and indicates when criteria for success have been achieved.

1.3 SUMMARY OF OFFSETTING FEATURES

The following constructed features will create or enhance fish habitat to offset losses occurring as a result of the Whale Tail Pit and Whale Tail Pit Expansion Projects. Complementary measures (research projects) included in the offsetting plan for Whale Tail Pit are also summarized. Further details are provided in the *Whale Tail Pit - Fish Habitat Offsetting Plan* (March, 2018 and its Appendix C, May 2018) and the *Whale Tail Pit Expansion Project Fish Habitat Offsetting Plan* (March, 2020).

1.3.1 Constructed Offsets

1.3.1.1 Rock Shoals and Road Scarification

Placement of rock material to change lake basin substrate from fine or mixed to coarse (i.e., the creation of rock shoals) is a commonly used fish habitat enhancement technique. In the dewatered area of Whale Tail Lake (Figure 1), roads and jetties will be scarified or converted to coarse substrate as necessary to create shoal-like features. In addition, an 8.7 ha network of shoals (termed grid shoals based on their conceptual design pattern) will convert a portion of the North Basin to higher-value habitat. Works will be conducted prior to the start of reflooding (est. 2026) and be accessible to fish post-reflooding (est. 2042).

1.3.1.2 Water Retention Sills and Flooding

During the operations period for the Whale Tail site, flooding of terrestrial zones in Whale Tail Lake (South Basin) and areas to the southwest is required for water management purposes (Figure 1). Flooding was initiated in 2019 and was complete in 2020. The majority of fish habitat offsets for the Whale Tail Pit and Whale Tail Pit Expansion Projects will be obtained by constructing two permanent water control structures (sills) to maintain elevated water levels in this area in perpetuity.

Prior to the pit reflooding period (est. start 2026) while Whale Tail Lake North Basin is still dry, one sill will be constructed just upstream (east) of Mammoth Dike. Once the Whale Tail Dike and Mammoth Dike are breached and flows resume their natural direction from Whale Tail Lake to Mammoth Lake, this feature will ensure that water levels in the re-flooded Whale Tail Lake remain at 1 m higher than baseline conditions, creating approximately 46.6 ha of new aquatic habitat. This sill is associated with offsetting for the Whale Tail Pit Project, and is further described in the *Whale Tail Pit - Fish Habitat Offsetting Plan* (C. Portt and Associates, 2018a).

Similarly, a sill is planned to be constructed between lake A18 and Whale Tail Lake. This structure will maintain water levels in the southwest flood zone (A18 – A22 & A63, termed “Lake A18” in the offsetting plan) at 1.3 m above baseline, creating approximately 31.35 ha of permanent aquatic habitat. This sill is associated with offsetting for the Whale Tail Pit Expansion Project, and is further described in the *Whale Tail Pit Expansion Project Fish Habitat Offsetting Plan* (ERM, 2020).

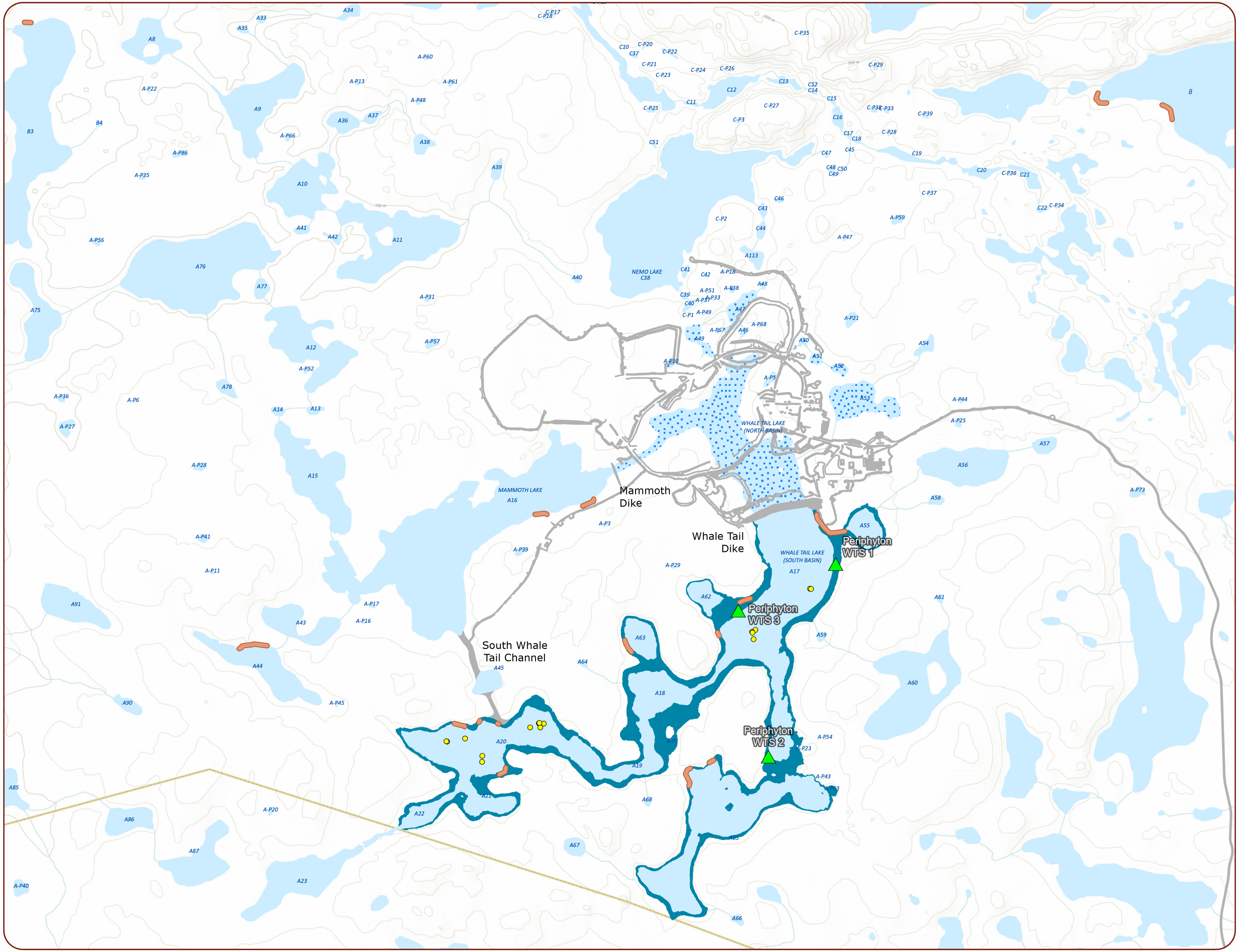
PROJECT: DA11-062-08

CLIENT: Agnico-Eagle Mines Ltd. Meadowbank Division

DATE: 12, February 2022

DRAWN BY: Janel Sauder/Nicole White

Figure 1: 2021 FHOMP Monitoring Locations - Whale Tail Site



Legend

- Periphyton Stations
- Water Chemistry Stations
- Shoreline Electrofishing Routes
- Infrastructure
- Dewatered Lake

South Whale Tail Lake Elevations

- Baseline Water Level
- Flood Zone

0 0.5 1 km

N

UTM Zone 17N NAD83

AGNICO EAGLE

DOUGAN & ASSOCIATES ECOLOGICAL CONSULTING & DESIGN

PROJECT: DA11-062-08

CLIENT: Agnico-Eagle Mines Ltd. Meadowbank Division

DATE: 12, February 2022

DRAWN BY: Janel Sauder/Nicole White

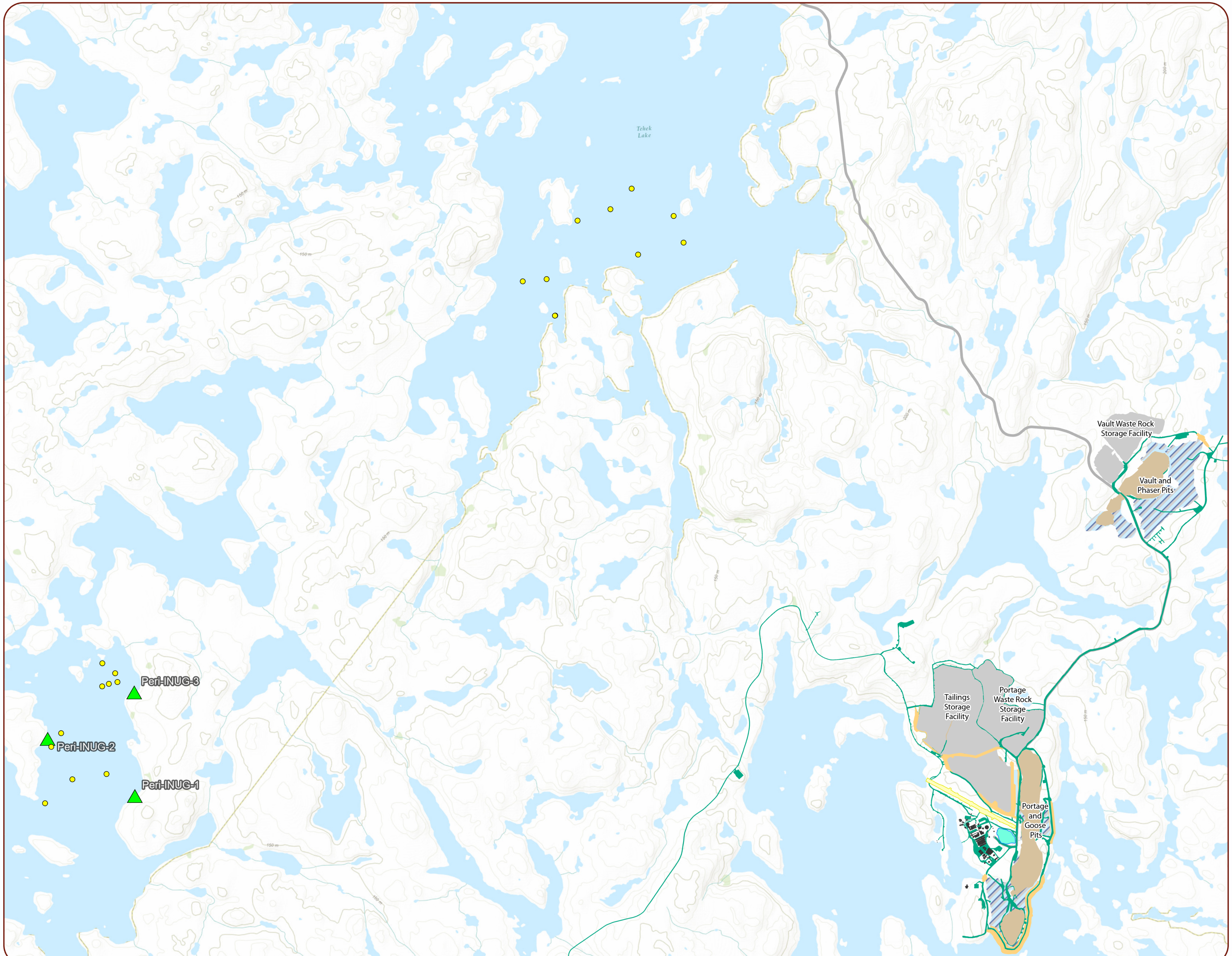


Figure 2: 2021 FHOMP Monitoring Locations - Inuggugayualik & Pipe Dream Lake

Legend

- Water Chemistry Stations
- Periphyton Stations

Mine Plan

- Dewatered Lake
- Roads
- Pits
- Airstrip
- Dikes
- Facilities
- Waste Rock & Tailing Storage Facility
- Stormwater Management Pond

0 1.5 3 km

N

UTM Zone 17N NAD83

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1.3.2 Complementary Measures

A suite of complementary measures (research projects) is included as offsetting for the Whale Tail Pit Project. These studies continue to inform Agnico Eagle's offset planning in Nunavut as well as fish and fish habitat monitoring techniques. The complete scope of these complementary measures including methods, timelines, deliverables, and budgets is provided in Appendix C (May, 2018) of the *Whale Tail Pit - Fish Habitat Offsetting Plan* (C. Portt and Associates, 2018a). Studies include:

1. Assessment of changes in aquatic productivity and fish populations due to flooding of Whale Tail South and downstream lakes during operations
2. Assessment of impacts of the Baker Lake wastewater outflow on aquatic systems including fish and fish habitat
3. Literature review and field validation of northern lake fish habitat preferences
4. Arctic grayling occupancy modeling
5. Pit lake habitat use assessment
6. eDNA methods development

These programs have been developed in collaboration with research partners at academic institutions, and generally consist of 2-5 year study plans initiated in 2018 or 2019. One study (pit lake habitat use assessment) is planned to begin in or around 2027 at the Meadowbank site, following completion of flooding for the Phaser and Vault Pits, unless a suitable alternate research site is identified in the nearer term.

1.4 SCHEDULE FOR MONITORING

The proposed schedule for monitoring of offsets is described in the FHOMP (Agnico Eagle, 2021 – under review).

Generally, a pre-offsetting monitoring program is underway from 2021 – 2023, prior to construction of any permanent sills, to determine effectiveness of flooded terrestrial zones as fish habitat. For monitoring years 2021 and 2022, results are provided in a data report format, with a final assessment to be completed following the 2023 season (Table 2).

Final monitoring for constructed offsets is planned to begin after 2026, when construction of the permanent sills is complete. Monitoring for the A18 flood zone and Whale Tail South flooding offsets will occur from 2027 – 2036 and monitoring for the Whale Tail North flooding and shoals offsets will occur from 2040 – 2052.

Progress updates for complementary measures will be provided annually.

Table 2. General schedule of assessments conducted under the pre-offsetting ecological monitoring program for the Whale Tail site.

Component	2021	2022	2023
Water quality - from CREMP	✓	✓	✓
Periphyton	✓*	✓	✓
Small-bodied fish – shoreline habitat	✓	✓	TBD**
Large-bodied fish - foraging and spawning habitat			✓
Report	Data report (by Mar. 31, 2022)	Data report (by Mar. 31, 2023)	Final analysis (by Mar. 31, 2024)

**Pilot study*
***TBD depending on strength of results through 2022*

SECTION 2 • MONITORING METHODS

2.1 CONSTRUCTED OFFSETS

Constructed habitat offsets for the Whale Tail Pit and Whale Tail Pit Expansion Projects consist of rock shoals and two water retention sills to maintain specified flood levels. The monitoring plan for these habitat features consists of both physical and ecological components. Monitoring of physical components is intended to confirm and report compliance with requirements of the associated Fisheries Act Authorizations to construct specific habitat offsets. Ecological monitoring will be conducted to assess the effectiveness of these features in counterbalancing HADD of fish habitat. A complete description of scheduled monitoring to assess physical structure and ecological function of the offsetting features is provided in the FHOMP, and assessments completed in 2021 are described below. Because small-bodied fish assessments were also completed in the first year post-flooding (2020) as part of complementary measures Study 1, those methods and results are included here as supplemental data.

2.1.1 Physical Structure Monitoring

Once permanent offsetting features are constructed, physical monitoring will include an assessment of flood zone area (ha flooded, using measured water levels), shoal area, and stability of the features. No physical structure monitoring is specified in the FHOMP for 2021. However, a review of water levels in the flooded Whale Tail South area is provided here to identify current flood conditions. This information provides context for the ongoing pre-offsetting ecological monitoring of flood zone habitat and will assist in the eventual final analysis of flood zone habitat suitability.

Currently, water levels within the operational Whale Tail South flood zone are measured every 3 h by piezometers installed in the Whale Tail Dike.

2.1.2 Ecological Monitoring

As indicated in Table 2, ecological monitoring was conducted in 2021 in support of the pre-offsetting ecological monitoring program. This included water quality monitoring under the existing CREMP, a periphyton monitoring pilot study, and small-bodied fish population assessments for the newly created shoreline habitat. Details of these assessments including dates, locations, field methods and laboratory analyses are described below.

2.1.2.1 Flood Zone Water Quality

Water quality analyses conducted under the CREMP are used to confirm suitable water quality within the Whale Tail area terrestrial flood zones that form part of offsetting plans. Under this program, mid-water column samples in areas > 5 m deep are collected at two sites from each of two formerly separate lakes in the flood zone (Whale Tail South and A20), up to 5x/year.

Complete methods are described in the 2021 CREMP Report (Azimuth, 2022), an Appendix of the Meadowbank Complex 2021 Annual Report to the NIRB.

2.1.2.2 Periphyton Growth

The periphyton community consists of a collection of microorganisms, including algae, that grow attached to or in very close proximity to submerged substrate. Colonization of the community occurs over time, with rates depending on factors such as nutrient and light availability. Periphyton is an important food source for benthic invertebrates and has been broadly used as an indicator metric in biomonitoring protocols for many years.

For the Whale Tail site, colonization of periphyton is monitored to provide a commentary on growth in flood zone habitat compared to reference areas. Historical data analysis as part of the 2015 CREMP design update (Azimuth, 2016) has indicated that due to extreme natural variability, statistical comparisons of periphyton on in-situ substrate (e.g., submerged rock faces) are not well suited for receiving environment monitoring in this area. As a result, periphyton monitoring for the Whale Tail site will incorporate two components:

1) Visual surveys in designated locations within newly created flood zones to qualitatively assess progression of periphyton development on underwater rock substrate.

2) Deployment of artificial substrate samplers to confirm whether colonization rates are comparable to reference systems, indicating that a healthy periphyton community can become established.

Since periphyton sampling using artificial substrate has not previously been used at the Meadowbank site, a pilot study was conducted in 2021 with a limited set of lakes to assess feasibility and field test methods. Visual surveys will commence in 2022.

2.1.2.2.1 Artificial Substrate - Pilot Study Methods

According to MacDonald et al. (2012), a single sample location is sufficient for seasonal periphyton monitoring in small Arctic lakes. The pilot study was conducted in order to test methods (e.g., amount of substrate required) and conduct a power analysis to confirm number of sample locations per lake, moving forward.

Artificial Substrate Samplers – Each periphyton sampler consisted of two Plexiglas slides (30.5 cm x 20.3 cm each) suspended side-by-side approximately 25 cm below a wood float. A metal weight (U-bolt) was attached to each slide to help keep them suspended vertically in the water column (Figure 3).

Figure 3. Artificial substrate sampler for periphyton pilot study in 2021.

Sample Locations & Dates – For the pilot study, three periphyton samplers (each holding 2 Plexiglas slides) were deployed in flood zone locations in Whale Tail South (WTS-1, WTS-2, WTS-3), and three samplers were deployed in the reference system, Inuggugayualik Lake (INUG-1, INUG-2, INUG-3) (Figure 1 & 2). Each sampler was deployed in a shoreline location in 1 – 2 m water depth and secured using an anchor weight affixed to one end of the wood float (Figure 4).

WTS samplers were deployed on July 8 and retrieved on September 8. INUG samplers were deployed on July 27 and retrieved on September 4.

Figure 4. Artificial substrate periphyton sampler in-situ.

Sample Collection and Analysis – Periphyton samplers were retrieved from the water and placed in labelled sample bags after tether ropes were removed. Care was used not to disturb periphyton on the slides during this process. Slides were stored in a dark cooler with ice packs prior to processing (periphyton removal) onsite. Upon return to the onsite laboratory, Plexiglas slides were removed from sample bags and placed on a clean tray for processing, one by one. Both sides were scraped clean using a scoopula and all material was rinsed back into the sample bag using a small amount of deionized water (Figure 5). Sample bags were sealed and stored frozen prior to and during shipping to the accredited laboratory for analysis. Analysis for chlorophyll-a as a relative measure of biomass was performed by ALS Laboratories using procedures modified from EPA Method 445.0. Briefly, chlorophyll-a content by mass is determined using a 90% acetone extraction followed with analysis by fluorometry.

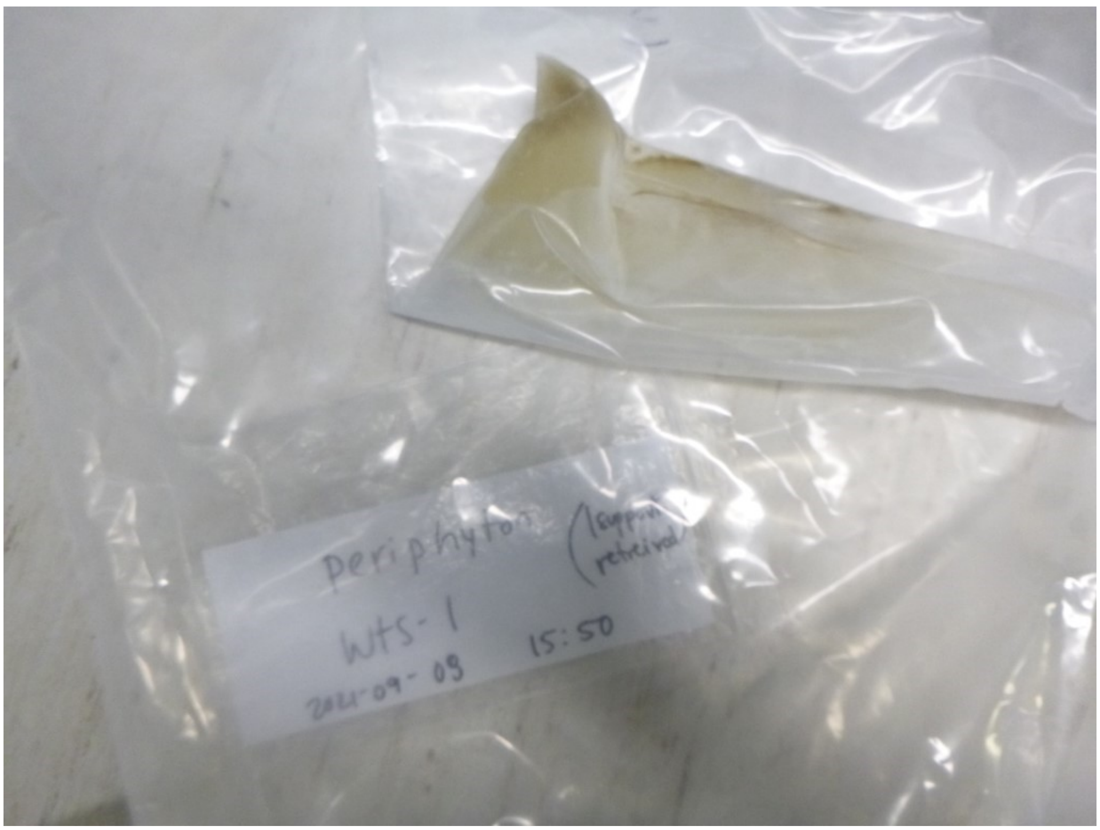

Figure 5. Periphyton sample for location WTS-1, prepared for shipping.

2.1.2.3 Fish Use

In 2021, field assessments for the pre-offsetting ecological monitoring program focused on use of shoreline habitat by small-bodied species, as described below. In future years, deeper water habitat use by large bodied species will also be assessed.

2.1.2.3.1 Flood Zone Habitat – Habitat Types 2 & 3 (Shoreline)

To determine effectiveness of offsetting habitat, relative abundance and population dynamics indicators for resident small-bodied fish in flooded shoreline areas (inundated areas, or terrestrial habitat that are part of the lake and have undergone physical changes due to flooding) are evaluated and compared to reference sites.

According to the Whale Tail site Habitat Evaluation Procedure (HEP; Portt & Associates, 2018; ERM, 2020), the newly created shoreline in Whale Tail Lake will provide primarily foraging habitat for Ninespine Stickleback (*Pungitius pungitius*) and Slimy Sculpin (*Cottus cognatus*), as Habitat Types 2 and 3. This assumption was tested beginning in the first year post-flooding (2020[3]) and 2021 by shoreline electrofishing at selected flooded lake areas (Whale Tail Lake – South Basin, A63, A65, and A20), downstream areas (Mammoth Lake), and reference areas (Lake 8, A44, B03) (Figure 1, Table 3).

Electrofishing is an active fishing technique that uses pulsed direct current to initiate an involuntary swimming action in fish. When exposed to the electrical field, fish become oriented toward the electrofisher and involuntarily swim towards the anode and are collected with a dip net. In 2020 and 2021, a team of two field biologists, one person with a backpack electrofisher, another with a dip net, collected fish by wading along representative shorelines in Habitat Types 2 and 3 of flooded lakes and reference lakes. When time and access allowed, electrofishing was conducted until a minimum of 30 Slimy Sculpin were collected per lake (number selected by the research team for Study 1 (Section 2.2) in 2019 using on *a priori* power analysis to determine minimum sample size). In 2020, the team collected more than 30 Slimy Sculpin in all lakes, with the exception of A63. In 2021, this objective was met in Whale Tail Lake (n=32), A63 (n=29), Mammoth Lake (n=31) and at the Reference Lake (B03, n=30), but not in flooded lakes A65 and A20, nor in reference lakes Lake 8 and A44.

CPUE was calculated as the number of fish/100 seconds of electrofishing. All fish collected were identified to the lowest taxonomic level possible (typically to species), length and weight were recorded, and fish were archived. Age will be determined in a sub-set of individuals.

[3]Small bodied fish assessments were conducted in 2020 under complementary measures Study 1, and while not specifically part of the FHOMP requirements, results are included here as supplemental data.

Table 3. Summary of shoreline electrofishing effort under the FHOMP pre-offsetting ecological monitoring program for the Whale Tail site.

Habitat Type	Waterbody	2020		2021	
		Dates	Duration (EF hr:min)	Dates	Duration (EF hr:min)
Flooded	Whale Tail South	Aug 26	3:35	Aug 14, 15, 16	0:56
	A63	Aug 26	0:40	Aug 16	0:41
	A65	Aug 27	4:32	Aug 12	0:53
	A20	Aug 27	3:31	Aug 10	1:39
Downstream	Mammoth Lake	Aug 21, 25	15:19	Aug 17	2:23
Reference	Lake 8	Aug 23, 24	5:42	Aug 15	1:24
	A44	Aug 29	6:42	Aug 13	1:14
	B03	Aug 29	1:36	Aug 14, 18	1:12

2.2 COMPLEMENTARY MEASURES

As required by Fisheries Act Authorization HCAA-16-00370, complete annual progress reports on complementary measures are provided to DFO by May 30 of the following year, including methods and preliminary results.

An interim update is provided in this report for each project, along with a description of activities of the MFRAG in the preceding year. These interim updates will focus on general activities and identifying progress towards study completion, and do not include specific methods and results.

SECTION 3 • RESULTS & DISCUSSION

3.1 CONSTRUCTED OFFSETS

3.1.1 Physical Structure Monitoring (Water Levels)

Likely due to record rainfall during the primary flood year (2019), peak water levels exceeded predictions in July of that year (up to 155.8 meters above sea level; masl), but did not reach the maximum predicted final flood elevation of 156.0 masl; Figure 6). In 2020 and 2021, water levels were lower than FEIS model results, which predicted a mean monthly elevation of 156.0

masl would be maintained throughout the operations period. This change resulted from an amendment to the final design[4] of the South Whale Tail Channel, which is the outlet of the Whale Tail South flood zone (to Mammoth Lake). The design change included a decrease in the original inlet elevation by 0.5 m, to 155.3 masl, in order to reduce peak water levels against the Whale Tail Dike. Operational water levels moving forward are therefore predicted to be lower than the 156.0 masl mark. To date (2020 and 2021) flood-zone water levels have ranged between approximately 155.0 and 155.75 masl over the course of a year.

Despite a reduction in operational water levels compared to FEIS predictions throughout the flood zone, measured elevations are the same as or exceed those that will eventually be maintained permanently for offsetting purposes, following sill construction.

For Whale Tail Lake, offsetting plans assume an increase to 154.02 masl from a baseline of 153.02 masl (baseline determined from July 21, 2011 CanVEC imagery). Current operational water levels in late July are in the range of 155.2 – 155.4 masl, or about 1.2 – 1.4 m higher than they will be post-offsetting. As a result, shoreline habitat in Whale Tail Lake – South Basin that is evaluated now under the pre-offsetting ecological monitoring program may be considered representative of, but not identical to, post-closure shoreline habitat in this area, once water levels are drawn down by 1.2 – 1.4 m.

For Lake A18, offsetting plans assume an increase to 155.3 masl from a baseline of 154.0 masl in A18 (at the A18 sill)[5]. Since the Whale Tail South Channel which is the current outlet for the flood zone was constructed at 155.3 masl, current operational water levels align with this plan and no significant change in water levels or shoreline habitat would be expected following sill construction.

[4] The completed construction summary report for the South Whale Tail Channel is available through the NWB public registry here: ftp://ftp.nwb-oen.ca/registry/2%20MINING%20MILLING/2A/2AM%20-%20Mining/2AM-WTP1830%20Agnico/3%20TECH/D%20CONSTRUCTION/D16/South%20Channel/

[5] For lakes further upgradient from A18 that will be permanently joined to it by flooding (A19 – A22 plus A63), baseline water elevations are higher than A18, so flooding to the planned 155.3 masl increases water depths in those lakes by less than 1.3 m. For example, baseline depths in A22 were measured at 155.0 masl in the offsetting plan, so flooding to 155.3 masl adds 0.3 m above baseline.

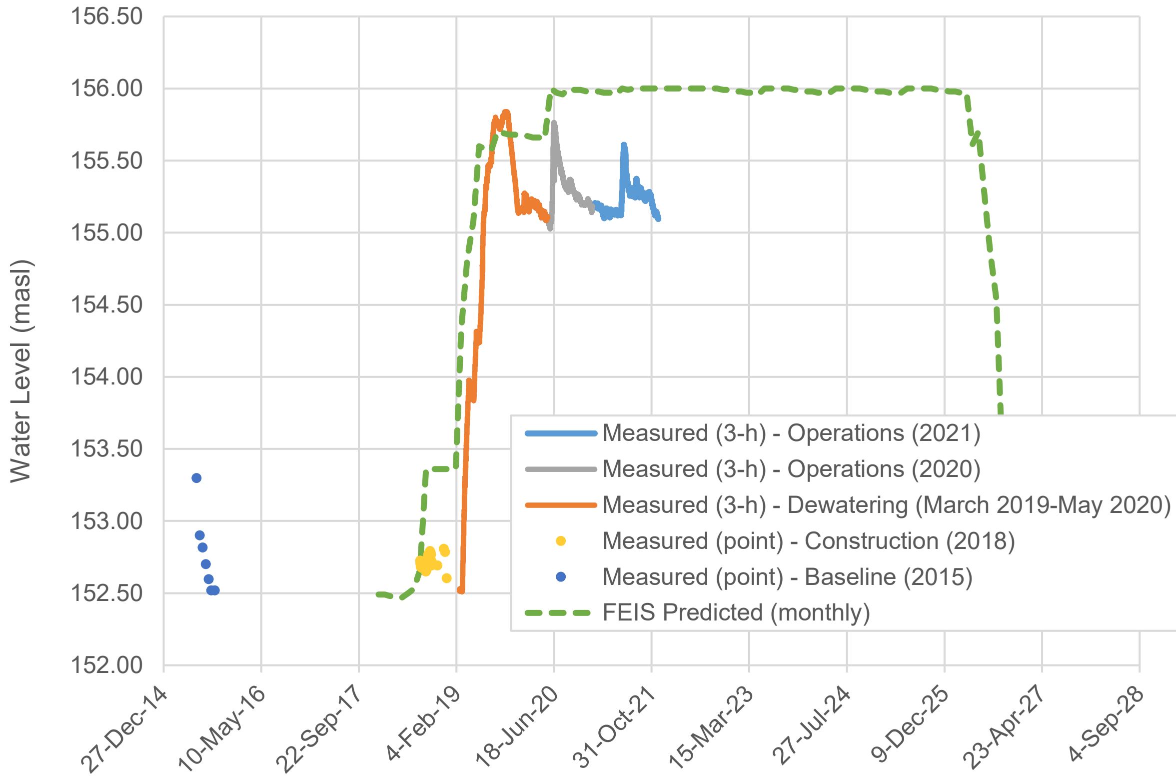

Figure 6. Measured and predicted water levels in the Whale Tail South flood zone (point measurement by GPS survey, 3-h interval by piezometer, or modeled monthly mean, as indicated). Predicted water levels from FEIS Addendum for the Whale Tail Pit Expansion Project, Appendix 6-O, Table D-14 (Agnico Eagle, 2018b).

3.1.2 Ecological Monitoring

3.1.2.1 Flood Zone Water Quality

Complete results of annual water quality monitoring within the Whale Tail flood zone (samples collected in Whale Tail South (WTS) and A20) are presented in the 2021 CREMP Report (an appendix of the 2021 Meadowbank Complex Annual Report to the NIRB). Results will be compiled and presented in the FHOMP context to support analyses as part of the final pre-offsetting ecological monitoring report in 2024 (*Impact Analysis of Fish Habitat from Flooding*).

Briefly, in 2021, some exceedances of CREMP water quality triggers and significant differences from baseline/reference conditions were observed in WTS and A20 for:

- Ionic compounds (TDS and constituent ions such as calcium, magnesium, potassium),
- Nutrients (total Kjeldahl nitrogen, total phosphorus, total organic carbon and dissolved organic carbon),

- Lithium (WTS only).

Similar to results seen over the years at the Meadowbank study lakes, these trends represent increases above baseline/reference conditions only; except for total phosphorus, none of these analytes have CCME effects-based guidelines for the protection of aquatic life and the observed concentrations are not expected to result in adverse ecological effects (Azimuth, 2022).

The observed trends for nutrients are also generally consistent with FEIS Addendum predictions for increased nutrient concentrations in WTS (Agnico Eagle, 2018b). As an indicator parameter for nutrients, predicted and measured concentrations of total phosphorus to date are shown in Figure 7. While some measured concentrations of phosphorus have exceeded monthly FEIS predictions in WTS, all were within an order of magnitude (the level of uncertainty assigned to these predictions in the FEIS), and measured concentrations have remained below or within predicted trophic levels to date. Concentrations in 2019 – 2021 were predicted to remain in the oligotrophic range, or 4 – 10 µg/L.

Under the CREMP, phytoplankton community sampling is also conducted at the same time as the water chemistry program. Along with the above-described changes in nutrient concentrations, an increase in phytoplankton biomass was observed in WTS (10% increase; not statistically significant) and A20 (222% increase; statistically significant) relative to baseline/reference in 2021 (Figure 8). These results follow a statistically significant increase compared to baseline/reference for WTS in 2019, and an apparent but not statistically significant increase in 2020. This increase in lower trophic level production was predicted in the FEIS Addendum, but not quantified (Agnico Eagle, 2018b).

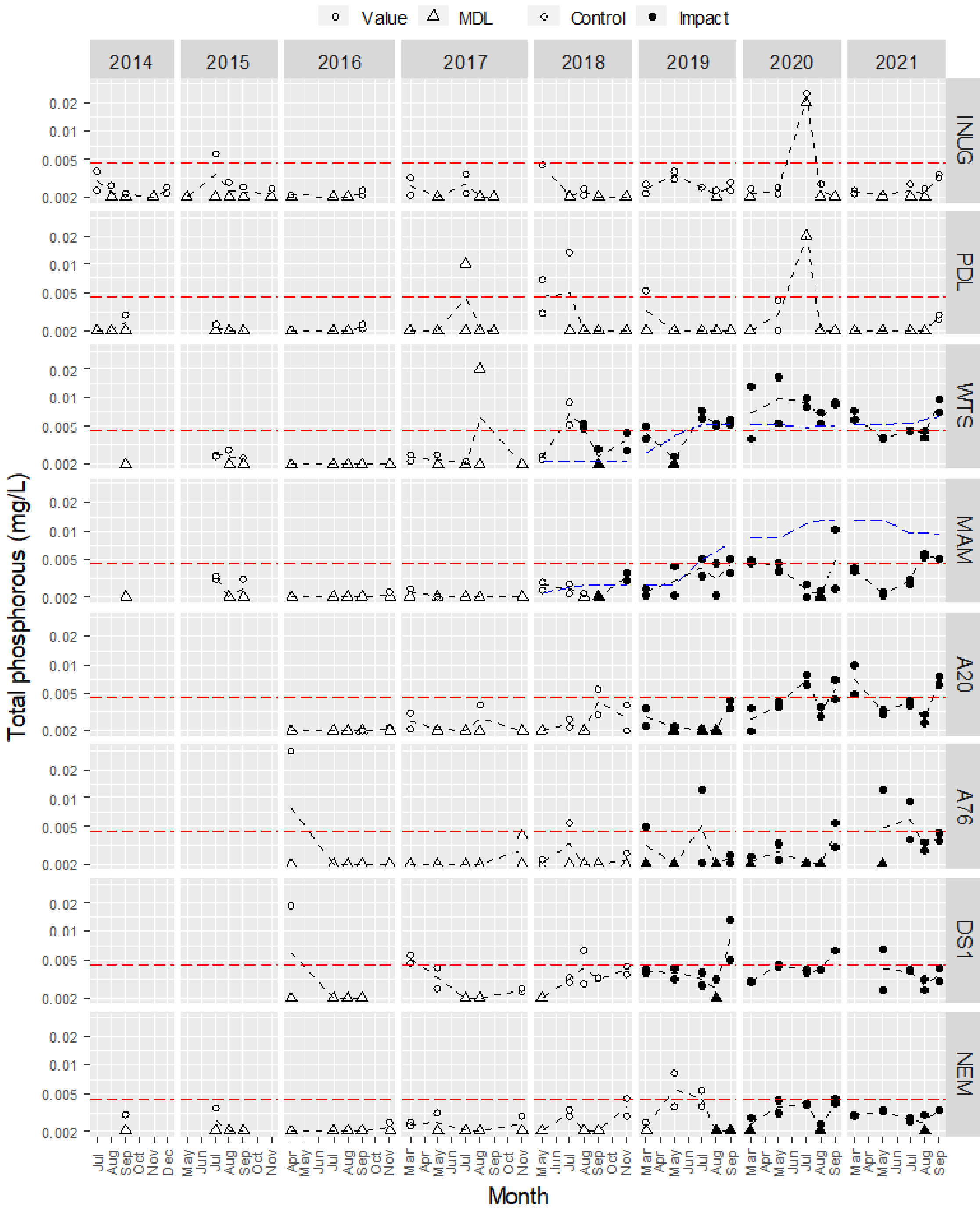

Figure 7. Total phosphorus in water samples from Whale Tail study area lakes since 2014. Red dashed line indicates CREMP trigger value. Blue dashed line indicates FEIS Addendum model prediction. The detection limit was adjusted for some July 2020 samples from 0.002 mg/L to 0.010 mg/L or 0.020 mg/L. Figure from Azimuth (2022).

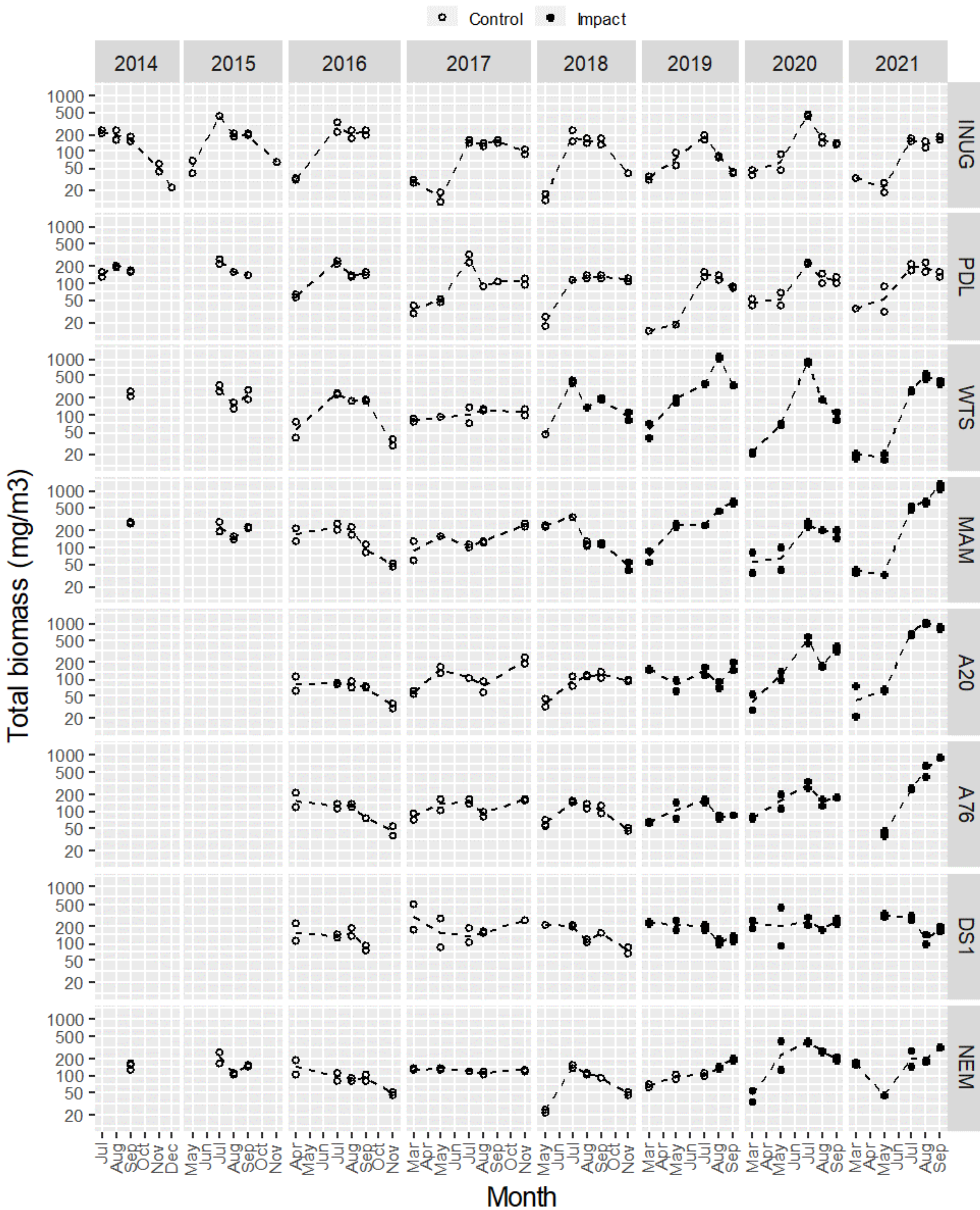

Figure 8. Total phytoplankton biomass (mg/m[3]) from the Whale Tail Pit study lakes since 2015. Figure from Azimuth (2022).

3.1.2.2 Periphyton Growth

Sampler Design - In total, six periphyton samplers were deployed (each holding two Plexiglas sample slides) and four were ultimately recovered. One was eventually located onshore, and one was never located. Three of the four recovered samplers were in the flood zone system of Whale Tail South, and one was in the reference system, Inuggugayualik Lake. Among the four retrieved samplers, two only had one Plexiglas slide remaining attached.

Despite the high rate of sample substrate loss, Agnico is of the opinion that some small adjustments to the pilot sampler design can be made to mitigate the problems that were encountered, which primarily resulted from high winds shifting the weighted wood floats from their initial position. The following changes are suggested to improve sampler design:

- Where feasible, samplers will be attached to a rebar stake that has been driven into the lake bed. Where this is not feasible, a system with two anchors or a heavier single anchor will be used.

- To better affix Plexiglas slides, light chain or braided polypropylene rope will be considered, along with potentially deploying a collection of smaller slides rather than a single larger slide.

- Supplemental samplers may be deployed to provide extras that would be available for analysis in the event of primary sampler loss.

Periphyton Biomass –. Both sides of all plexiglass slides were scraped, resulting in a total sample area of 1238.3 cm^2 per slide (Table 4). For stations WTS-2 and INUG-2, two Plexiglas slides were retrieved per station but the scraped sample was combined onsite due to an error in communication so the combined area of two slides is used in calculations.

Table 4. Periphyton chlorophyll-a results for artificial substrate samplers. Slide dimensions were 30.5 cm x 20.3 cm, and both sides were scraped to remove accumulated periphyton.

Station	Total Slide Area Sampled (cm^2)	Total Chlorophyll-a (µg)	Chlorophyll-a (µg/cm^2)
WTS-1 (flood zone)	1,238.3 (1 slide)	38.4	0.031
WTS-2 (flood zone)	2,476.6 (2 slides)	232	0.094
WTS-3 (flood zone)	1,238.3 (1 slide)	44.1	0.036
INUG-2 (reference)	2,476.6 (2 slides)	<1.0	ND

In general, the pilot study was successful in demonstrating that seasonal periphyton growth can be effectively measured on artificial substrate in the Whale Tail flood zone using Plexiglas slides of the size tested here. Measured chlorophyll-a content in flood zone samples was at least 38x the detection limit of 1 µg using this method.

While the lack of replication due to loss of sampling slides prohibits basic statistical comparison of results among WTS stations, the three samples were well within the same order of magnitude and differed by a maximum factor of just over 3x. While periphyton growth has not previously been quantified at the Whale Tail site, similar or greater variability in biomass as measured by cell counts was observed in co-located periphyton samples scraped from natural substrate in Second and Third Portage Lakes as part of the 2021 Meadowbank Habitat Compensation Monitoring Report (Agnico Eagle, 2022; an appendix of the 2021 Meadowbank Complex Annual Report to the NIRB) (e.g. the SP-DT reference station had a range of 182 – 463 µg/cm^2, n=6). Taken together, these preliminary results do suggest that variability of periphyton growth may not be greater between stations than within a station. This would align with the findings of MacDonald et al. (2012), which indicated that periphyton sampling at a single location within a small Arctic lake is sufficient.

Results of the chlorophyll-a analysis for the reference lake sample in Inuggugayualik Lake were below detection limits. However, INUG samplers were deployed late in the season (July 27, compared to July 8 for WTS), and only one of three samplers was retrieved, so there is uncertainty as to whether seasonal growth is not measurable in reference systems, or whether earlier deployment of samplers would allow sufficient biomass accumulation.

While overall results are preliminary and the 2021 study was planned as a pilot to assess methods feasibility only, the observed differences in periphyton biomass between WTS and INUG are in line with FEIS Addendum predictions for increased nutrient concentrations and primary productivity in WTS (Agnico Eagle, 2018b), and 2021 CREMP results, which showed increased concentrations of both nutrients and phytoplankton biomass in flood zone lakes compared to baseline/reference (Azimuth, 2022; as described in Section 3.1.2.1).

Conclusions and Next Steps – Despite the high rate of sample substrate loss, this pilot study was successful in demonstrating that seasonal periphyton biomass as represented by chlorophyll-a concentration can be effectively measured using artificial substrate samplers in the Whale Tail flood zone. The lack of growth on slides deployed in the reference system (INUG-2) suggests that seasonal growth may be too low to be effectively assessed by chlorophyll-a methods in area lakes unimpacted by flooding. However, the reference station sampler was deployed significantly later in the short summer season, and only one sample was available so that conclusion is preliminary. Nonetheless, it is expected that offsetting criteria for success with regards to quantitative endpoints for periphyton can be assessed using this method, by measuring periphyton seasonal growth within the flood zone as compared to the growth or lack of growth in reference systems. These data combined with visual periphyton assessments, water quality analyses, and fish population assessments will provide a wholistic understanding of flood zone habitat characteristics.

Adjustments to the sampler design will be implemented in 2022 to improve sample collection rate and confirm preliminary conclusions drawn from the 2021 pilot study. Although initial results suggest that sampling in a single location may be sufficient, the 2022 design will include samplers deployed in a minimum of two stations within each target flood zone basin

(Whale Tail South Basin and A20) to align with CREMP water quality stations (Azimuth, 2022). Statistical power analysis conducted with the 2021 WTS and INUG periphyton data in Table 4 indicates that a minimum of three samples per station would be required to detect differences in periphyton chlorophyll-a between them (when Station 1 (WTS) mean = 0.064+/-0.029 µg/cm^2; Station 2 (INUG) mean = 0.0002 µg/cm^2 (1/2 detection limit), α = 0.05 and β = 0.2). Therefore in 2022, four sample slides will be installed per station to facilitate basic statistical analyses of differences between stations, allowing for loss of one slide per station.

3.1.2.3 Fish Use

Fish assessments of shoreline Habitat Types 2 and 3 using backpack electrofishing in 2020 and 2021 demonstrated residence of small-bodied fish and evidence of growth and survival in this newly flooded habitat. Both Ninespine Stickleback and Slimy Sculpin were present in flooded shoreline habitat in greater abundance and catch per unit effort (CPUE) than reference lakes in 2020 and 2021 (Table 5 and Figure 9; 2021 raw data provided in Appendix C). In flood zone lakes, Ninespine Stickleback CPUE was notably higher in 2020 compared to 2021. These data will be further analyzed and discussed in the context of multi-year results as part of the final report following the 2023 field season.

During shoreline electrofishing in Whale Tail Lake in 2021 a number of large-bodied fish were also captured incidentally and identified as year 1 to 4+ Lake Trout (*Salvelinus namaycush*), Arctic Char (*Salvelinus alpinus*), Burbot (*Lota lota*) and Round Whitefish (*Prosopium cylindraceum*). Size metrics were not specifically recorded but the observations are shown in Table 5. These fish were consistently caught near sloped shorelines with mixed, gravel cobble substrate.

Table 5. Abundance of Ninespine Stickleback, Slimy Sculpin and other fish by-catch from shoreline electrofishing.

Habitat Type	Waterbody	2020		2021		
		NSSB	SLSC	NSSB	SLSC	Other
Flooded	Whale Tail South	33	33	15	32	LKTR, RNWH, BURB, ARCH
	A63	34	0	16	29	-
	A65	35	35	3	12	LKTR, RNWH, ARCH,
	A20	35	37	19	6	ARCH
Downstream	Mammoth	7	34	32	31	-
Reference	Lake 8	0	34	1	10	ARCH, Sal.
	A44	3	34	4	8	LKTR
	B03	1	34	9	30	ARCH, LKTR, BURB
Total		**148**	**275**	**98**	**158**	-

NSSB = Ninespine Stickleback; SLSC = Slimy Sculpin; LKTR = Lake Trout; ARCH = Arctic Char; RNWH = Round Whitefish; BURB = Burbot; Sal. = Salmonid species

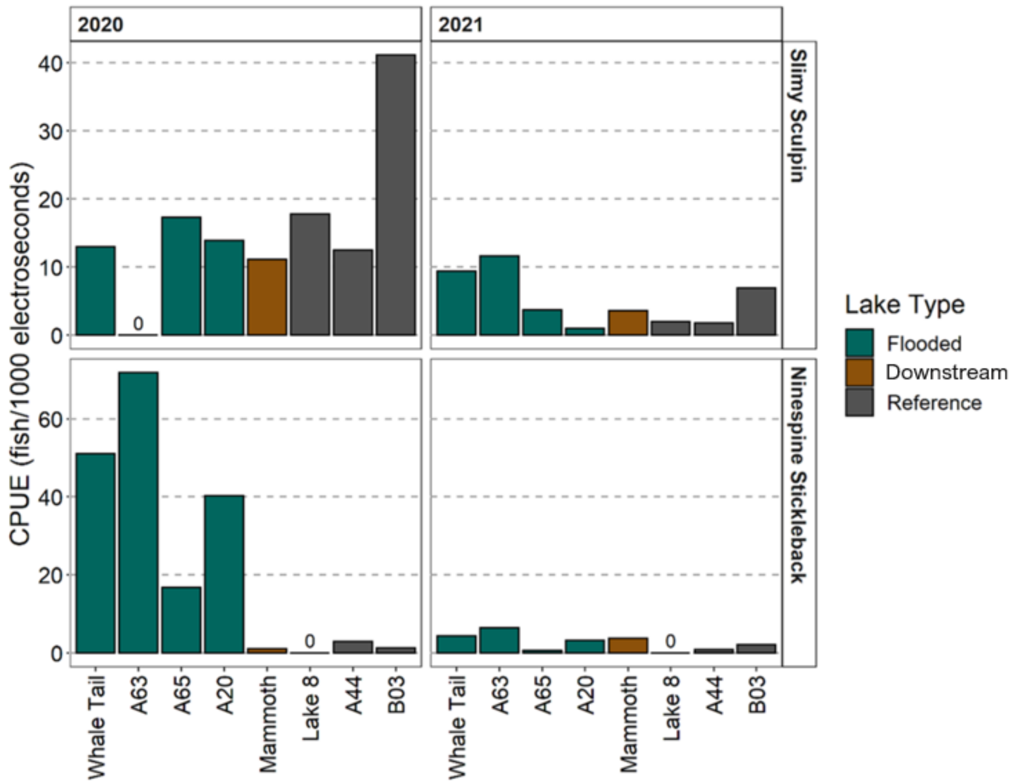

Figure 9. Catch per unit effort of Slimy Sculpin and Ninespine Stickleback collected in 2020 and 2021 at study lakes.

The length-frequency distribution of Ninespine Stickleback collected in flooded lakes demonstrated an increase in age-class between years and a shift in the length-frequency distribution (Figure 10). The overall larger fish observed in 2021 compared to 2020 demonstrates growth of fish within the population. Similarly, the year-over-year shift in length-frequency distributions for Slimy Sculpin in flooded lakes (Figure 11) indicates that overall larger fish were observed in 2021 as compared to 2020.

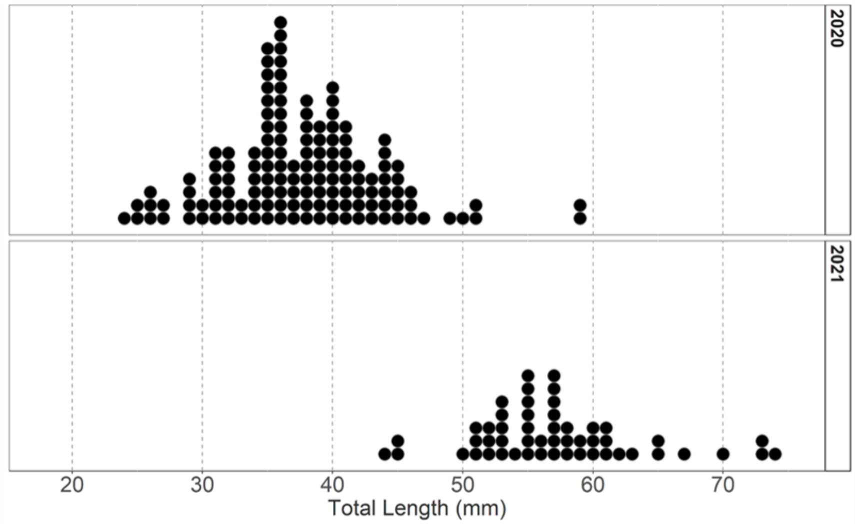

Figure 10. Ninespine Stickleback length-frequency distributions for fish collected in flooded lakes.

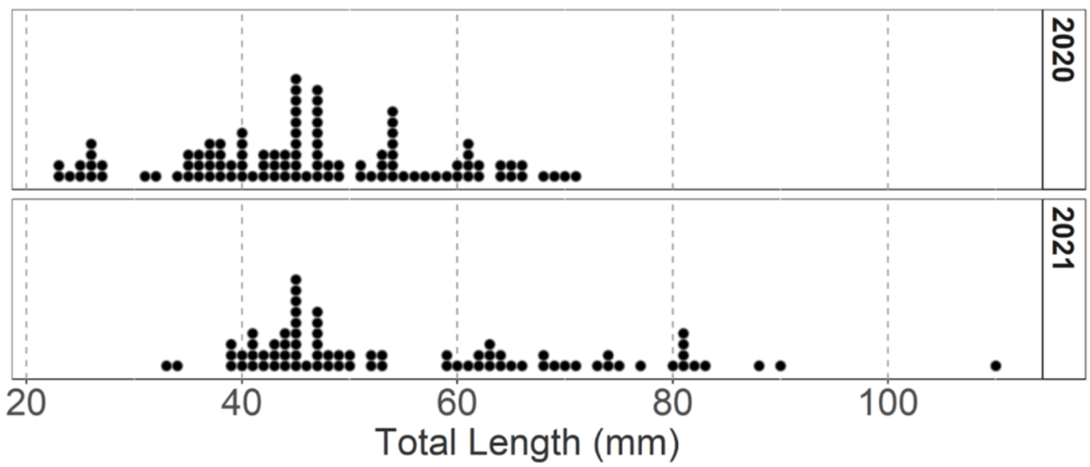

Figure 11. Slimy Sculpin length-frequency distributions for fish collected in flooded lakes.

3.2 COMPLEMENTARY MEASURES

An update is provided here on activities of the MFRAG along with a summary of progress for each research study in 2021. Full research methods are documented in annual progress reports provided to DFO by May 30 annually.

3.2.1 Activities of the MFRAG

As part of the Fish Habitat Offsetting Plan for Whale Tail Pit (C. Portt and Associates, 2018a), MFRAG was conceptualized to provide a forum for input from key stakeholders. The MFRAG meets annually to review project progress reports, propose and approve or reject new projects or project components, and assess whether criteria for success have been met.

In 2019, Agnico Eagle confirmed interest in MFRAG participation by DFO, the Kivalliq Inuit Association (KIA), and the Baker Lake Hunters and Trappers Organization. As planned in the Fish Habitat Offsetting Plan for Whale Tail Pit, Appendix C (C. Portt and Associates, 2018a), Agnico Eagle also identified a third party external advisor (Dr. Kelly Munkittrick, University of Calgary) who will participate in all MFRAG activities. A draft Memorandum of Understanding and Terms of Reference (TOR) were developed by Agnico Eagle and reviewed by all parties. The initial meeting of the MFRAG was held on December 12, 2019 in Montreal, Quebec. Representatives from all member groups were in attendance. The group received presentations by lead researchers involved in each study, and had the opportunity for questions, comments, and open discussion. Each MFRAG member group was requested to provide written comments, if any, by February 28, 2020. Written comments were distributed to research study leads for consideration.

In 2020, the MFRAG TOR were finalized, and signed by all parties as of March, 2021. The second annual meeting of the MFRAG was held by video conference due to COVID restrictions on December 2, 2020, with all member groups participating (Agnico Eagle, DFO, KIA, BLHTO). As in 2019, the group received presentations by lead researchers involved in each study, and had the opportunity for questions, comments, and open discussion. Each MFRAG member group was requested to provide written comments, if any, by January 13, 2021. Written comments were again distributed to all member groups and the research study leads for consideration. No major concerns with research study progress were raised during the meeting or in follow-up comments.

In 2021, the third annual meeting of the MFRA was held by video conference due to COVID restrictions on December 14, 2021, with all member groups participating. As in previous years, the group received presentations by lead researchers involved in each study, and had the opportunity for questions, comments, and open discussion. Each MFRAG member group agreed to provide written comments, if any, by January 25, 2022. Written comments were again distributed to all member groups and the research study leads for consideration. No major concerns with research study progress were raised during the meeting or in follow-up comments.

The participant list, agenda, and notes from the 2021 MFRAG meeting are provided in Appendix A.

3.2.2 Study 1 - Assessment of Changes in Aquatic Productivity and Fish Populations Due to Flooding (H. Swanson)

3.2.2.1 Research Objectives

This research study aims to understand changes in fish population productivity and habitat use during and after flooding occurs, as determined through relative abundance and/or biomass and condition factor within the resident fish population. Since flooding activities were initially planned to occur over a relatively short term (2-3 years), the study focuses on small-bodied fish, which are expected to react first to changes in nutrient profiles.

Changes in productivity will be related to water quality variables and changes in lake morphometry (especially area). Use of newly flooded habitats will be assessed and related to habitat characteristics.

3.2.2.2 Research Methods & Summary of Activities

In 2018, 2019, 2020, and 2021 the study focused on the collection of baseline data (2018) and flooding year 1, 2, and 3 data (2019, 2020, 2021) for small-bodied fish species (Slimy Sculpin, Ninespine Stickleback) within the Whale Tail South area. Shoreline electrofishing was completed for small-bodied fish in up to 10 waterbodies in the area of Whale Tail Lake: Whale Tail Lake, Mammoth Lake, A63, A20, A65, A44, A76, B03, DS1 and Lake 8 (Figure 12). Monitoring endpoints that were selected for analysis included abundance, length, weight, condition, age, catch per unit effort, and weight-at-age.

In addition, the University of Waterloo team collected annual supplemental water quality data, which will be used to support the interpretation of fish population data. Water and sediment quality data collected under compliance monitoring programs will similarly be used in this assessment.

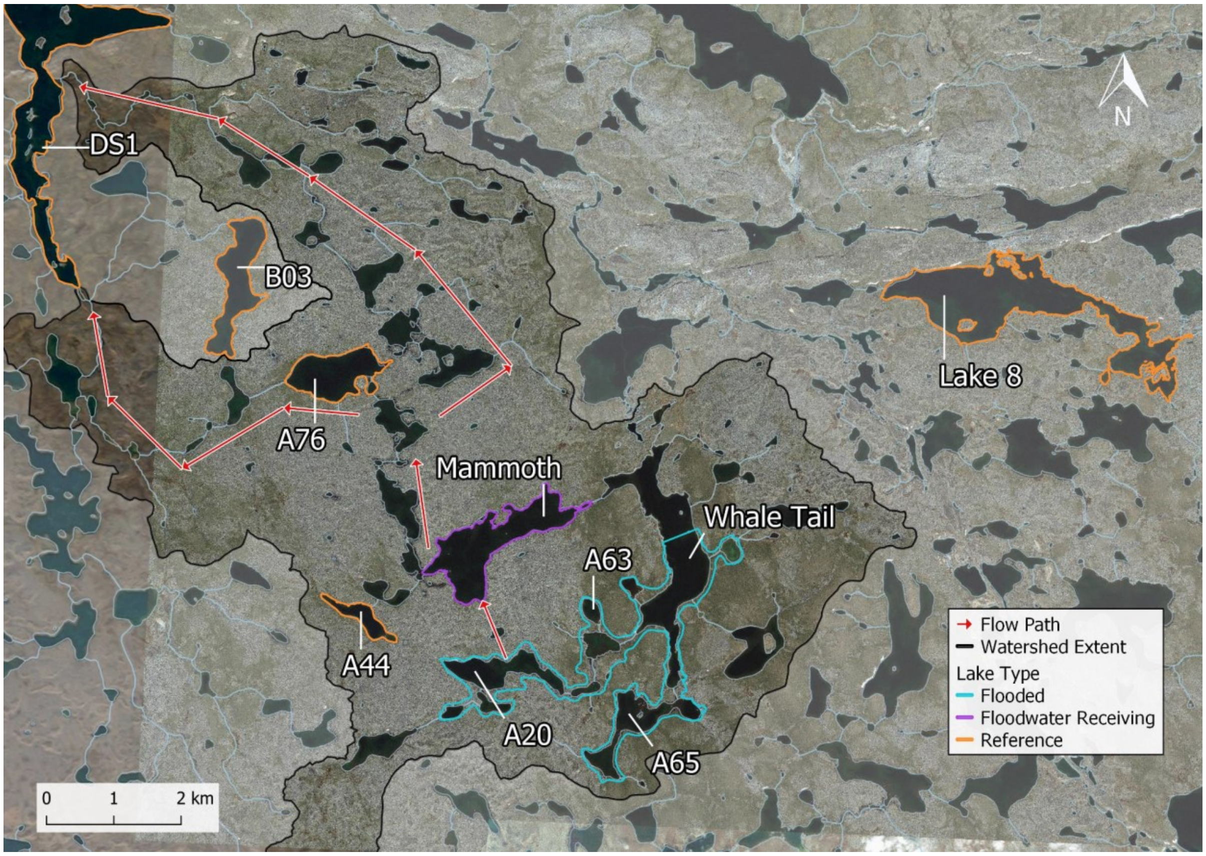

Figure 12. Whale Tail Productivity study area.

3.2.2.3 Study Completion

This study was scheduled for completion (final journal article submission) in 2022. However, due to COVID-related staffing restrictions, a one-year extension is anticipated, with final journal article submission in 2023. The final field season was completed on time as originally scheduled, in 2021.

3.2.3 Study 2 – Assessment of Impacts of the Baker Lake Wastewater Outflow on Fish Productivity and Fish Habitat (H. Swanson)

3.2.3.1 Research Objectives

A 5-year research program lead by Dr. Rob Jamieson (Dalhousie University) is underway to assess the current status of the wastewater treatment system in the hamlet of Baker Lake and develop designs for upgrades. As part of this holistic assessment, key questions related to understanding fish health, fish habitat, nutrient status and fish productivity are included as offsetting for the Whale Tail Pit project. The fish and fish habitat portion of the study is being conducted by Dr. Heidi Swanson, from the University of Waterloo.

The following objectives specific to fish and fish habitat have been developed:

1. Quantify the current fish habitat, fish health and fish productivity in the Arctic wastewater system.

2. Quantify changes in fish habitat, fish health and fish productivity associated with Arctic wastewater treatment system upgrades.

3.2.3.2 Research Methods & Summary of Activities

General study methods follow Environmental Effects Monitoring (EEM) protocols to assess changes in large-bodied fish population health and habitat that occur as a result of wastewater treatment upgrades. Supplemental methods similar to those employed in Study 1 will be used to further assess changes in productivity in small-bodied fish, which may occur under shorter time frames. Specific target lakes include those within the current wastewater flow path, as well as a reference system (Figure 13). This study is focusing on:

- Finger Lake,
- Lagoon Lake,
- Airplane Lake,
- Baker Lake,
- the connecting streams, and
- reference lakes.

Figure 13. Baker Lake wastewater study lakes and reference lakes.

In 2018, 2019 and 2021, the University of Waterloo completed field reconnaissance and collected water quality, sediment samples, fish tissue samples, and conducted presence/absence surveys.

2018:

- Reconnaissance year
- Collected water samples and sampled fish in Finger Lake and Airplane Lake
- Evaluated potential reference sites

2019:

- Selection of reference lakes
- Shoreline electrofishing, minnow trapping, gill netting in 5 waterbodies (Lagoon, Finger, Airplane Lake, R1 and R2)
- Fish presence/ absence
- Collected Ninespine Stickleback and Arctic Grayling for health indicators, otoliths, and tissue
- Working in collaboration with University of Manitoba and Dalhousie University, collected water quality samples and submitted for analysis.

2020: Due to restrictions under the COVID-19 pandemic, the 2020 field season could not proceed. The study period has thus been extended by one year.

2021:

- Shoreline electrofishing, minnow trapping, gill netting in 5 waterbodies and the outlet of Airplane Lake (Lagoon, Finger, Airplane Lake, Airplane Lake creek, R1 and R2).
- Fish presence/ absence.
- Collected Ninespine Stickleback and Arctic Grayling for health indicators, aging structures (i.e., otoliths), and tissue.
- Collected sediment chemistry data.
- Collected periphyton and zooplankton data.
- Working in collaboration with University of Manitoba and Dalhousie University, collected water quality samples and submitted for analysis.
- Completed otolith microchemistry analysis at University of Manitoba.
- Data analysis, interpretation, thesis and manuscript writing.

3.2.3.3 Study Completion

With a 2-year extension due to COVID delays, the full study is now scheduled for completion in 2027, but the baseline fish assessment report is expected to be complete in 2023.

3.2.4 Study 3 – Literature Review and Field Validation of Northern Lake Fish Habitat Preferences (S. Doka)

3.2.4.1 Research Objectives

Habitat preferences of northern fish species are not well understood, which causes significant uncertainty in habitat-based offset calculations. This study aims to:

1 - Identify literature data gaps in habitat associations of Meadowbank-area lake fishes such as Lake Trout, Arctic Char, and Round Whitefish,

2 - Field-test a variety of methods for filling data gaps.

3.2.4.2 Research Methods and Summary of Activities

This study was planned to be conducted over three years, from 2018 – 2020. Methods include a literature review, data gap analysis, and field programs to assess various sampling techniques for identifying fish habitat associations. Field surveys occurred in 2018 and 2019.

Literature Review and Gap Analysis - Following closely the Centre of Environmental Evidence guidelines for systematic literature review, a graduate student with Lakehead University under the co-supervision of Dr. Mike Rennie and Dr. Susan Doka reviewed primary and grey literature sources as well as unpublished data (e.g., Golder & Associates 2016, DFO FishOut database) on 11 northern species, including Lake Trout (*Salvelinus namaycush*) Burbot (*Lota lota*), Lake Whitefish (*Coregonus clupeaformis*), Lake Cisco (*Coregonus artedi*), Round Whitefish (*Prosopium cylindraceum*), Arctic Char (*Salvelinus alpinus*), Arctic Grayling (*Thymallus arcticus*), Slimy Sculpin (*Cottus cognatus*), Ninespine Stickleback (*Pungitius pungitius*), Dolly Varden (*Salvelinus malma*) and Bull Trout (*Salvelinus confluentus*) with current fish distributions in lakes of Nunavut and the Northwest Territories (Mandrak, et al. in review) and expert input from individuals that have been in the field in recent years (C. Portt & Associates, 2018b). The data extracted from the review has been analyzed using appropriate statistical methods to synthesize the information by life stage (3 stages: spawning, nursery, juvenile/adult habitats) for the 11 northern fish species.

Field Programs - Fisheries and Oceans in partnership with Lakehead University conducted ten days of sampling (August 20-30, 2018) in the vicinity of the Amaruq mine camp. The objective of this work was to perform reconnaissance sampling to test efficiencies and logistical challenges of using conventional methods used by scientific consultants and government researchers in the south to assess habitat and fish communities. A variety of equipment was used to meet this objective including, a multi-probe water quality sonde (EXO), passive and active fish sampling gears in both lakes and connecting channels (e.g., minnow traps, GoPro video footage, backpack electrofishing, drift nets) and hydroacoustic surveys (BioSonics MX) for physical habitat mapping (e.g., depth and substrate). The latter was conducted to complement hydroacoustic fish distribution data collected by Milne Technologies (mid-July 2018). Troubleshooting these methods in the field during 2018 informed how to standardize methods for fish habitat sampling in the North (Arctic Region) and how to proceed with habitat and fish assessment pilot tests during the 2019 field season.

Based on year one field tests and literature review results, field work in year two (2019) focussed on pilot testing methods to fill data gaps around habitat associations for small-bodied fishes, while assessing novel or alternative sampling approaches. The 2019 field program consisted of an analysis of Visible Implant Elastomer tagging methods for use in mark-recapture studies to evaluate stream habitat preferences, as well as deep water electrofishing, near-shore electrofishing, and netting techniques. Those programs were conducted over two study periods, in late June and August/September. Analysis of the 2019 field trial results continues.

3.2.4.3 Study Completion

The MSc thesis fulfilling objective 1 of this study (literature data gap review) was completed in September, 2020 (Hancock, 2020). Final reporting for this study including result and recommendations of field trials was initially planned for 2020 but was delayed due to DFO staffing constraints under the COVID-19 pandemic. The final report submission has now been extended two years, to 2022.

3.2.5 Study 4 – Arctic Grayling Occupancy Modelling (H. Swanson)

Objectives of this work were the development of occupancy models for Arctic grayling in the Meadowbank region, and a comparison of habitat predictors in this area with those observed in the NWT. Understanding the potential for occupancy of fluvial systems by fish species based on readily measurable habitat characteristics could facilitate and improve the accuracy of environmental impact assessment and offset planning.

This study was conducted from 2018 – 2021, and final reports consist of an MSc thesis submitted to the University of Waterloo in April, 2020 (Ellenor, 2020), and a peer- reviewed manuscript published in November, 2021 (Appendix B; Ellenor et al., 2021). These documents contain the complete research objectives, methods, and results. Briefly, from Ellenor et al. (2021):

> *Visual surveys of young-of-year Arctic grayling were conducted in 48 streams near Baker Lake, Nunavut, Canada. Occupancy modeling was used to relate stream habitat and landscape variables to fish presence/absence. The best predictors of occupancy were total area of contributing upstream lakes and landcover (upland/lowland); stream basins with larger contributing upstream lake area and more lowland cover were more likely to be occupied. Results suggest that occupancy reflects reliability of stream connectivity throughout the open water season and across years. The occupancy model developed here can adequately predict stream suitability for young-of-year Arctic grayling using lake area and land classification data that are remotely accessed. This may lessen the considerable*

> *financial and logistical constraints of conducting field research on Arctic grayling in the vast Barrenlands and facilitate more directed field programs to inform conservation and mitigation plans.*

Publication of the peer-reviewed manuscript fulfills this study's criteria for success, and it is now considered complete.

3.2.6 Study 5 – End-pit Lake Habitat Suitability Assessment

Fish use of re-flooded pit areas with good connectivity to natural systems is not well understood, yet these areas may represent a significant opportunity for fish habitat offsetting. Since multiple pits of various sizes at the Meadowbank site are planned to be reflooded in the relatively near term (2027 – 2029), there is an opportunity to thoroughly characterize fish use of pit lake habitat and population growth in re-flooded lakes through a research program. This study will aim to characterize fish use of new pit lake habitat in relation to habitat and water quality variables, and particularly in relation to reference systems. The research team and program details will be developed by the MFRAG prior to study initiation (est. 2026).

While study methods and research members will not be determined until closer to study initiation, a literature review was provided to DFO in February 2019 in fulfillment of Condition 4.2.1.3 of FAA 16-HCAA-00370.

3.2.7 Study 6 – eDNA Methods Development (J. Stetefeld and M. McDougall)

3.2.7.1 Research Objectives

eDNA methods present a potentially useful tool for rapid and non-invasive assessments of fish communities but have not been significantly developed or validated for Arctic systems. The main goal of this project is to develop and optimize monitoring tools based on eDNA metabarcoding technology to assess fish species assemblages (presence/absence and relative abundance) in the Kivalliq region.

Objectives are:

1. Development and optimization of the eDNA metabarcoding technique adapted for the arctic environment as a substitute for current fish species determination approaches.

2. Producing guidelines for handling and analyzing of samples and deliver the method and provide training to the local community.

3. Produce long-term reliable and precise baseline data on the distribution of aquatic associated fish species in the Amaruq mine site lakes using developed eDNA technology.

4. Producing data on the physiochemical properties of the lake water including dissolved mineral content to understand if any changes in stated parameters affect the eDNA/fish assemblage results.

5. Examine the impact of flooding Whale Tail Lake South Basin with the coincident changes in physiochemical properties of the aquatic area (e.g., increase in turbidity, dissolved solids) on the fish population using developed eDNA technique.

6. Collecting baseline eDNA and water quality data on lakes nearby Amaruq mine site outside the mining activity (potential candidates include B3 or DS1) and use them as a control for population changes.

3.2.7.2 Research Methods & Summary of Activities

This study involves a 5-year plan to develop and utilize an eDNA metabarcoding approach to measure fish assemblages in the Amaruq area. Environmental DNA metabarcoding technology will be developed and optimized to detect fish species including Arctic Char, Arctic Grayling, Lake Trout, Round Whitefish, Burbot, Slimy Sculpin, Ninespine Stickleback, Hybridized Lake Trout/Arctic Char and analyze their relative abundances. For water quality data, temperature, pressure, dissolve oxygen, pH, salinity, conductivity, and dissolved metals including Cu/Zn/Cd/Fe/Hg/Mn will be measured.

The first two rounds of sampling were completed before significant in-water construction (July 2017). The second round of sampling was done in August, 2018, during construction of the Whale Tail Dike. The third round of sampling was done in August 2019, during flooding of the Whale Tail South area. Additional sampling was completed after flooding (2021). The results will be used to assess the influence of mining activity on changes in fish species populations, as measured through eDNA methods.

In furthering the training objectives of this project, eDNA sampling workshops were held at the University of Manitoba in February 2019 and 2020, with 4 and 7 members of the Kivalliq Inuit community in attendance, respectively. The 3-day workshops featured of number of lecturers in the eDNA community, as well as a hands-on DNA extraction laboratory, and a foundation for further involvement of the Inuit community in eDNA sampling was laid. In the 2019 season, two of the trainees from the program assisted in sample collection. This field training will set the stage for sampling independent of the University of Manitoba.

3.2.7.3 Study Completion

This study is on track for completion in 2023, as originally planned, though publication of the initial methods manuscript has been extended from 2020 to 2023, largely due to COVID-related restrictions on laboratory access and difficulties encountered in refining analytical methods.

SECTION 4 • ASSESSMENT OF SUCCESS

4.1 CONSTRUCTED OFFSETS

Year 1 monitoring was conducted in 2021 under the FHOMP's pre-offsetting ecological monitoring program (Agnico Eagle, 2021). According to this Plan, results are provided here in a data report format, with a final assessment to be conducted following the 2023 monitoring year. Results will be evaluated in the context of the Plan's criteria for success at that time. However in general, results in 2021 indicate suitable water quality for aquatic life within the Whale Tail flood zone, and presence of small bodied fish populations in newly created shoreline habitat at rates no lower than reference areas.

4.2 COMPLEMENTARY MEASURES

Criteria for success for each research project are focussed on publication of study results in the peer-reviewed literature, or similar primary sources. In 2021, Study 4 – *Arctic Grayling Occupancy Modelling* was completed and met these criteria with publication of the manuscript attached here as Appendix B.

As a result of COVID-related delays or restrictions, original timelines for study completion have been extended by two years for four of the six studies (Table 6). In the interim, several studies have been presented at academic conferences, and two MSc theses publications have been completed.

Table 6. Target study publication dates and publication or presentation references. **Overall study completion delayed 1-2 years due to COVID or other interruptions in 2020 and 2021.

Study	Study Initiation	Target Final Publication Submission Date		Publications and Presentations
		Original	Current	
Study 1: Productivity (H. Swanson)	2018	2022	2023**	Ellenor, J., Portt, C., and Swanson, H.K. 2019. Variation in Slimy Sculpin (*Cottus cognatus*) monitoring endpoints at six Barrenland lakes in central Nunavut. Poster presentation. Canadian Conference for Fisheries Research on January 3-6, 2019.
Study 2: Wastewater (H. Swanson)	2019	2021/2024	2023/2027**	Bronte McPhedran presented preliminary findings and research methods at Young Environmental Scientists SETAC conference in Texas, on March 9-11, 2020.
Study 3: Habitat Preferences (S. Doka)	2018	2020	2022**	MSc Thesis: Hancock H., 2020. Physical habitat associations of fish species in the Kivalliq region of Nunavut, Canada. Lakehead University, Orillia, Ontario. Available at: http://ceelab.ca/wpcontent/ uploads/2020/10/Hannah final- thesis-10132020.pdf Two presentations have been given at scientific fora by the graduate student, Hannah Hancock of Lakehead University: at Canadian Conference for Fisheries Research in London ON in January, 2019 and at the American Fisheries Society -Ontario Chapter meeting in Orillia ON in February, 2019.
Study 4: Arctic Grayling Occupancy (H. Swanson) - **COMPLETE**	2018	2021	2021	**Manuscript**: Ellenor, J.R., P.A. Cott and H.K. Swanson (2021). Occupancy of young-of-year Artic grayling (*Thymallus arcticus*) in Barrenland streams. Hydrobiologia (published online 15 November 2021).

Study	Study Initiation	Target Final Publication Submission Date		Publications and Presentations
		Original	Current	
				Available at: https://link.springer.com/article/10.1007%2Fs10750-021-04742-3 MSc Thesis: Ellenor, J. 2020, June. Habitat use of young-of-year Arctic Grayling (*Thymallus arcticus*) in Barrenland streams of central Nunavut, Canada. University of Waterloo, Waterloo, Ontario. Available from http://hdl.handle.net/10012/15969. Ellenor J., Swanson, H. K., 2019. Factors influencing how Arctic Grayling (*Thymallus arcticus*) use Barrenland streams near Baker Lake, Nunavut. Platform presentation. ArcticNet Annual Scientific Meeting on December 2-5, 2019.
Study 5: End Pit Lake Habitat Use (Researcher TBD)	2027	2030-2034	2030-2034	-
Study 6: eDNA Study (J. Stetefeld/M. McDougall)	2018	2020 (interim), 2023 (final)	2023 (interim)**, 2023 (final)	-

SECTION 5 • ACTIONS

5.1 CONSTRUCTED OFFSETS

Monitoring in 2022 will follow the FHOMP (Agnico Eagle, 2021) for the pre-offsetting ecological monitoring period. As described in that document, this will include water quality as collected under the CREMP, periphyton visual assessments and expanded artificial substrate surveys, and shoreline electrofishing to assess small-bodied fish populations.

5.2 COMPLEMENTARY MEASURES

In 2022, field programs, laboratory assessments, and/or data analysis will continue for studies 2, 3, and 6. Delays in 2022 field programs may arise due to site travel restrictions under COVID-19.

Study 3 (literature review and field validation of northern lake fish habitat preferences) is planned to be completed, and final research reports produced.

A fourth meeting of the MFRAG is planned for November or December 2022.

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APPENDIX A

2021 MFRAG Meeting Agenda and Notes

Meadowbank Fisheries Research Advisory Group

December 14, 2021

(minutes added in red)

AGNICO EAGLE

2021 MFRAG MEETING

Welcome and thank you to all MFRAG members and presenters:

MFRAG Member Groups and Attendees

- Fisheries and Oceans Canada
  - Alasdair Beattie
  - Paul Harper
  - José Audet-Lecouffe
  - Christopher Shapka
- Agnico Eagle
  - Alexandre Lavallée
  - Leilan Baxter
  - Marie-Pier Marcil
- Kivalliq Inuit Association
  - Jamie Kataluk
- Baker Lake Hunters and Trappers Organization
  - Philip Putumiraqtuq
- Designated External Advisor
  - Kelly Munkittrick, Munkittrick Environmental

MFRAG Presenters

- Heidi Swanson, University of Waterloo
- Susan Doka, DFO Science
- Matthew McDougall, University of Manitoba
- Leilan Baxter, Agnico Eagle

2021 MFRAG MEETING

11:00 – 11:20 am

Greetings/introduction (Agnico)

11:20 am – 12:50 pm

Research presentations and question periods

1: Heidi Swanson – Arctic Grayling Occupancy Modelling (11:20 – 11:40)

2: Heidi Swanson – Changes in Aquatic Productivity (11:45 – 12:15)

(5 min break as needed)

3: Heidi Swanson – Baker Lake Wastewater Assessment (12:20 – 12:50)

(20 min break)

1:10 - 2:30 pm

Research presentations and question periods

4: Susan Doka –Habitat Preferences of Northern Fish Species (1:10 – 1:40)

5: Leilan Baxter – End Pit Lake Habitat Suitability (1:45 – 1:55)

6: Matt McDougall – eDNA Methods Development (2:00 – 2:30)

(5 Min Break)

2:35 – 3:00 pm

Summary and discussion of timelines and deliverables for each project.

Closing remarks

AGNICO EAGLE

Background – What is the MFRAG?

- In July 2018, DFO issued Fisheries Act Authorization 16-HCAA-03700 for Agnico's Whale Tail Pit Project.
- The fish habitat offsetting for this project includes a **suite of complementary measures (research projects)** developed by Agnico in consultation with DFO and the identified researchers.
- As part of this program, Agnico and DFO conceptualized an advisory group to review project progress and provide a forum for input from key stakeholders as these projects are carried out.
- Four of these projects are underway now at the Meadowbank site, one is complete, and one is in the concept phase.
- The main intent of the MFRAG is to **confirm projects stay on track** with regards to original objectives and timelines, and to allow members to provide any additional input from their unique perspectives.

2021 MFRAG MEETING

- Project topics

    1. Changes in fish populations in areas of terrestrial flooding at the Whale Tail site (2018 – 2022)
    2. Habitat suitability characterization for Arctic fish species (2018 – 2020, *now 2022*)
    3. Impacts of municipal wastewater discharge on fish health (2019 – 2025, *now 2026*)
    4. Characterization of fish habitat use in end pit lakes (est. 2027 – 2035)
    5. Methods development in eDNA monitoring of Arctic fish populations (2017 – 2022)
    6. Arctic grayling habitat occupancy modelling (2018 – 2021) - *complete*

- Today we will receive updates from the research teams on the progress of each project, and have an opportunity to ask questions.
- MFRAG members will also have the opportunity to review today's presentations and provide written comments later.

2021 MFRAG MEETING

- Please use this meeting to comprehend the status of each project, and ask any questions that will help in developing your eventual written comments (if any).
- As described in the TOR, key considerations for written comments are:
  - Has there been any change to the project's **overall goal or objectives**? If so, is this acceptable to you? The MFRAG will need to approve any major changes.
  - Do you have any comments on **study methods**? These have generally been developed by the researchers and approved in original study plans, but comments are welcome especially if/when new methods are introduced.
  - Any input on **community engagement** plans? These continue to evolve over the course of each project and any suggestions in light of Covid-19 limitations are especially helpful at this time.
  - Consider the overall project **timeline and deliverables**/criteria for success (publications). Do you have any major concerns about delays, if any?
  - Overall, **are you satisfied** that the study continues to be carried out as planned, or with acceptable changes?

2021 MFRAG MEETING

AGNICO EAGLE

1: Heidi Swanson – Arctic Grayling Occupancy Modelling

- Kelly – any plans for follow up, possibly combined with eDNA ?
- Heidi – not at the moment but open to it. Would like to understand the spatial range of this model and where we have to use different predictors (e.g. mountain areas) – one thing would be to go back to Gahcho Kue dataset and reanalyze with this model, as well as adding in Bill Tonn's data from Ekati
- Sue – sense that substrate and temperature doesn't make a big difference ?
- Heidi – in the first set of models % organic substrate and tempeature did matter, have rerun models with the temperature variable and it didn't change things. So it's not that they aren't important to the fish but they are well predicted by the landscape variables
- Susan – key factors for managers is that connectivity matters, but substrate less so?
- Heidi – yes getting flow rates dialled in is important (take home for industry too)
- Jose – if the study is pushed a bit further is there one direction you'd like to go?
- Heidi – there is some uncertainty around some predictions because it was difficult to get to streams with high upstream contributing lake area and low upland land cover, so some combinations of conditions weren't represented by the data. It would be really helpful to get those datapoints.

2: Heidi Swanson – Changes in Aquatic Productivity

- Leilan - Collecting habitat info during electofishing?
- Heidi – only superficially, not a major factor but will be able to provide some comment on habitat impacts
- Jose – how is flood zone habitat beneficial for large bodied fish?
- Heidi – some of the flooded esker areas have created good habitat for Arctic char and Lake Trout, and from other work we do know small bodied fish create food. I can't say for sure but it does seem that populations have not declined. The flooded esker habitat could create good spawning, rearing for large fish – follow up opportunity there.
- Jose – if you could expand what would you do?
- Heidi – large bodied fish is a very interesting question or using telemetry – evidence in NWT shows lake trout have a habit of a quick foray from deep to shallow habitat to feed. Interested in how much they would do the same thing in these lakes.
- Kelly – stickleback have increased, sculpin decline may just be access issue. What would you do differently if you were to do it again e.g. pit tagging sculpin?
- Heidi – yes could be an option, Sue's group was working on a bell electrofisher that could be interesting too. Or a portable electrofisher on an inflatable would provide some great data (sculpin use of deeper flood zones)
- Leilan – comparison of results to habitat variables, will be really interesting to compare to water levels
- Heidi – yes high level, not very detailed habitat info available

2021 MFRAG MEETING

3: Heidi Swanson – Baker Lake Wastewater Assessment

- Kelly – partition GSI/LSI by sex?
- Heidi – yes – further discussion to be had here, would like your assistance for Bronte
- Matt – what is limiting factor for temporal resolution? Does it need to be a large bodied fish?
- Heidi – we can get year over year data on fish, we started with marginal edge to make sure there is a relationship to water quality. What limits spatial resolution is 2 things – growth of the fish (tightly packed otolith) ,and concentration of the element in the otolith

4: Susan Doka –Habitat Preferences of Northern Fish Species

- Kelly – co-located fyke nets and electrofishing?
- Sue – will have to look at that but pretty sure they are co-located
- Kelly – wondering if the electrofishing is pushing fish into the fyke nets
- Sue – generally advocate for multiple methods which helps tease apart habitat associations
- Sue – interested to look into vegetated lake 8 habitat
- Jamie – deep water electrofisher – is it effective on all sizes of fish?
- Sue – it only caught small fish but we were just testing the method. Would be difficult for larger fish unless it just happened to swim across the ring. We wanted to see how deep the smaller fish go – hypotheses is they tend to live in more shallow environments but this method allows to monitor them in deeper areas.

5: Leilan Baxter – End Pit Lake Habitat Suitability

- Sue – possible collabs Paul Blanchfield and Jacob Brownscombe
- Matt – backfilling?
- MP – no plan for backfilling
- Sue – issues with water quality if there is no backfilling?
- Leilan – this would be considered in water quality modeling which as far as I recall didn't show any issues, the area is planned to be ok for fish
- Jose – no backfilling means more water to go in there – any issue with impacts on water levels
- Leilan – most flooding from natural inflows, from what I recall there is not predicted to be any impacts on downstream lake (Wally) which is very big

AGNICO EAGLE

6: Matt McDougall – eDNA Methods Development

- Leilan – are you analysing only large and small fish?
- Matt – yes, surprise to not see small one to come up
- Leilan – will you be able to know how confident you are that fish not detected are not there?
- Matt – yes will be able to quantify this confidence and we know the fish that can be found there
- Kelly – any trials with cages of fish to see how far from the fish you can detect eDNA?
- Matt – not up north but quite a bit of literature in the south (e.g. Japan – 1 km)
- Kelly – equally concerned you are not seeing a lot of the species, in these big lakes it's not clear how far those signals are going to go
- Matt – doing some tests with positive controls to make sure it's not our pcr that is missing some of these species
- Kelly – e.g. if people are doing fyke netting take samples near there?
- Matt – could be issue with cross contamination
- Kelly – then you'd have too many detections could be a better problem
- Jose – echo what Kelly is saying there, also any look at flowing water, small streams?
- Matt – not yet, assuming that wouldn't be an issue because these small streams aren't very long so you'd be getting whatever is coming from upstream as well
- Jose – is there anything you'd like to work on that you didn't get a chance to?
- Matt – try under ice sampling – DNA is at a steady state – shedding and degrading over the course of the year in response to temp, light, etc. So if you had some big ice cover I'm curious if DNA is higher or lower in the winter – this would also extend the sampling season

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Summary and discussion of project timelines, major changes, or other MFRAG member comments at this time.

Study	Principle Investigator	Timeline	Criteria for Success	Comments:
Aquatic Productivity	Swanson	2018 - 2022	Journal article submission (2022)	*Plan to extend publication to 2023* *Aim for an open source data report*
Northern Fish Habitat Preferences	Doka	2018 – 2020 *(ext. to 2022)*	CSAS or other technical document (2020 – *ext. to 2022*)	*Tech document – MFRAG 2022*
Baker Lake Wastewater	Swanson	2019 – 2025 *(ext. to 2026)*	Journal article submission (2025 - *ext. to 2026*)	*Baseline fish study complete 2022 - 2023*
End Pit Lake	TBD	Est. 2027 – 2035	TBD with MFRAG (likely peer-reviewed publications)	*No change*
eDNA	Stetefeld/ McDougall	2017 – 2023	Journal article submission (2020 and 2023 – ext. to 2022 for both?)	*Ext to 2022 – 2023 for both*
Arctic Grayling Occupancy	Swanson	2018 - 2021	Journal article submission (2021) - complete	*Complete*

2021 MFRAG MEETING

- Discuss submission date for written comments.
  - 4 “business weeks”? January 25
  - Ok for all

- Timing for next MFRAG meeting
  - Needs to be after May, summer can be difficult, so this time of year seems to work best
  - Ok for all.
- Thanks all for your participation
  - The meeting material (presentations) and minutes will be provided by Agnico to all members (December 17) for review and comment (Jan 25).
  - An annual summary of MFRAG activities based on those minutes will be included in Agnico’s Annual Report to the NIRB (March 31).

(Jose recalls we should schedule a meeting to discuss extension of the research programs)

End 2:30

AGNICO EAGLE

Thank you

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WORLD GOLD COUNCIL

APPENDIX B

Ellenor, J.R., P.A. Cott and H.K. Swanson (2021). Occupancy of young-of-year Artic grayling (*Thymallus arcticus*) in Barrenland streams. *Hydrobiologia* (published online 15 November 2021).
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Hydrobiologia
https://doi.org/10.1007/s10750-021-04742-3

PRIMARY RESEARCH PAPER

Occupancy of young-of-year Arctic grayling (*Thymallus arcticus*) in Barrenland streams

Jared R. Ellenor · Peter A. Cott · Heidi K. Swanson

Received: 10 May 2021 / Revised: 21 October 2021 / Accepted: 23 October 2021

Abstract Arctic grayling (*Thymallus arcticus*) is an iconic fish species that is present across the remote subarctic Barrenlands, yet our lack of understanding of their distributional patterns constrains predictions of anthropogenic effects on Barrenland populations. These adfluvial fish rely on seasonal lake-stream connections to migrate, spawn, and rear. We address knowledge gaps on what Barrenland stream attributes are suitable for rearing young-of-year Arctic grayling. Visual surveys of young-of-year Arctic grayling were conducted in 48 streams near Baker Lake, Nunavut, Canada. Occupancy modeling was used to relate stream habitat and landscape variables to fish presence/absence. The best predictors of occupancy were total area of contributing upstream lakes and land-cover (upland/lowland); stream basins with larger contributing upstream lake area and more lowland cover were more likely to be occupied. Results suggest that occupancy reflects reliability of stream connectivity throughout the open water season and across years. The occupancy model developed here can adequately predict stream suitability for young-of-year Arctic grayling using lake area and land classification data that are remotely accessed. This may lessen the considerable financial and logistical constraints of conducting field research on Arctic grayling in the vast Barrenlands and facilitate more directed field programs to inform conservation and mitigation plans.

Keywords Arctic grayling · Barrenland tundra · Stream habitat · Occupancy models

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Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10750-021-04742-3.

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Introduction

Basic knowledge of life history and habitat requirements are lacking for many fish species in northern regions, which makes it difficult to develop effective conservation policies, avoid or mitigate potential climate- or development-related impacts, and direct restoration efforts (Jones et al., 2017). Arctic grayling [*Thymallus arcticus* (Pallas, 1776)], is a colourful, iconic salmonid with a Holarctic distribution (Scott & Crossman, 1973). Valued by many stakeholders, including sport fishers (Scott & Crossman, 1973;

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Read & Roberge, 1984) and Indigenous communities (e.g., Kitikmeot Inuit Association, 2006), Arctic grayling is often a focal species in northern research studies and in environmental impact statements. In Arctic Barrenland landscapes, Arctic grayling often adopt a migratory adfluvial life history (e.g., Jones et al., 2003a, b; Baker et al., 2017), which makes them susceptible to habitat fragmentation and alterations in hydrologic flow and connectivity (Carl et al., 1992; Northcote, 1995). They also have low tolerance to increases in turbidity (Birtwell et al., 1984) and changes in water temperature (Haugen & Vollestad, 2000), which makes them useful as a sentinel species (e.g., McLeay et al., 1987; Reynolds et al., 1989; Phibbs et al., 2011; Veldhoen et al., 2014). Despite their vulnerability, there is a distinct paucity of data for this species, particularly in more remote parts of their range. The resulting critical knowledge gaps regarding ecology and life history of Arctic grayling preclude accurate or precise predictions regarding potential impacts of human-induced stressors, particularly in regions where habitat use is poorly understood, such as in the Canadian Barrenlands.

In the Barrenlands, life history and habitat use of Arctic grayling are influenced by the unique geomorphology and climate of the region. The Barrenlands are a vast tundra plain (estimated at over 700,000 km^2), stretching from Great Slave and Great Bear lakes in the Northwest Territories to the western coast of Hudson Bay in Nunavut, and are characterized by low elevation gradients, continuous permafrost, and abundant shallow lakes that are poorly integrated into large drainage systems (Baki et al., 2012). Many of the aquatic ecosystems in the Barrenlands are described as ‘chain-lake systems’, where streams can be thought of as short chains (a few hundred meters to a few kilometers) that provide critically important connections between lakes (Jones et al., 2003a). Adfluvial populations of Arctic grayling rely on the seasonally connected networks of lakes and streams to migrate, spawn, and rear (Jones & Tonn, 2004; Baker et al., 2017). Lakes, which provide foraging habitat for adults as well as overwintering habitat for all life stages, become disconnected in winter, when streams are frozen to the bottom (winter can last more than 8 months on the Barrenlands) (Jones et al., 2003a; Baki et al., 2012). During spring freshet, the rapidly melting snowpack recharges lake basins and reconnects lake-stream-river complexes, and adult adfluvial Arctic grayling out-migrate from lakes to spawning habitats in streams (Jones et al., 2003a). Adults typically migrate back to lakes shortly after spawning, before evaporation-induced declines in discharge affect connectivity for larger fish (Jones et al., 2003a). Young-of-year remain in streams to rear and feed throughout summer (Jones et al., 2003b, 2009; Baki et al., 2012), and must migrate from streams to lakes prior to freeze-up in fall (Jones et al., 2003b). Slow decreases in lake water levels and stream discharge throughout summer can lead to discontinuous or dry stream channels (Jones et al., 2003a; Woo & Mielko, 2007; Baki et al., 2012), and seasonal conditions can thus limit availability of suitable rearing habitat for YOY in natal streams. Understanding conditions and characteristics of Barrenland streams that support rearing YOY is critical for predicting recruitment, and can facilitate sound management of Arctic grayling in the Barrenlands.

Barrenland streams have diverse physical characteristics (Jones et al., 2003a), yet data on stream habitat preferences of Arctic grayling in this region are limited. To date, two studies have assessed habitat use of YOY Arctic grayling in Barrenland streams (Jones & Tonn, 2004; Baker et al., 2017). The authors of these studies found that water depth, water velocity, discharge, substrate, slope, amount of detritus, and cover by instream and overhanging vegetation affected presence of YOY Arctic grayling. The spatial scale investigated to date [approximately 120 km^2 and a total of 20 streams across four drainage basins in NWT, Jones & Tonn (2004) and Baker et al. (2017)], is small, and thus the full range of stream habitat conditions present in the Barrenlands was not fully represented. Additionally, studies to date have not quantified the influence of larger-scale landscape variables on habitat use by YOY Arctic grayling within streams. Regional factors, including variables that reflect climate, geology, and hydrology at scales larger than individual streams, are known to influence fish species composition and abundance (Hershey et al., 2006; Haynes et al., 2014; Laske et al., 2016), and effects of these factors on distributional patterns of Arctic grayling deserve further study.

The influence of geomorphic features on dispersal and habitat use of Arctic grayling has generally focused on occupancy in tundra lakes in Alaska (e.g., Hershey et al., 1999, 2006); streams have been less studied. Streams in the Barrenlands are largely colluvial, which means that fluvial processes are relatively ineffective at moving material and affecting channel morphology (Jones & Tonn, 2004), and attributes such as substrate and geomorphology reflect the immediate surrounding landscape. Soil characteristics and moisture regimes range from hydric graminoid peat, to mesic shrub tundra and xeric boulder lichen tundra (Campbell et al., 2012), which affect stream conditions. Wet and poorly drained landscapes may promote hydrologic connectivity and allow stream flows to persist through summer, whereas well-drained boulder fields can result in isolation of streams or subsurface stream flow. This is most prevalent in late summer, when water levels are lower (Jones et al., 2003a; Courtice et al., 2014). In a region where summer evaporation typically exceeds precipitation, landscape factors that affect stream connectivity, such as size and composition of contributing catchments, have the potential to influence suitability and habitat use for YOY Arctic grayling.

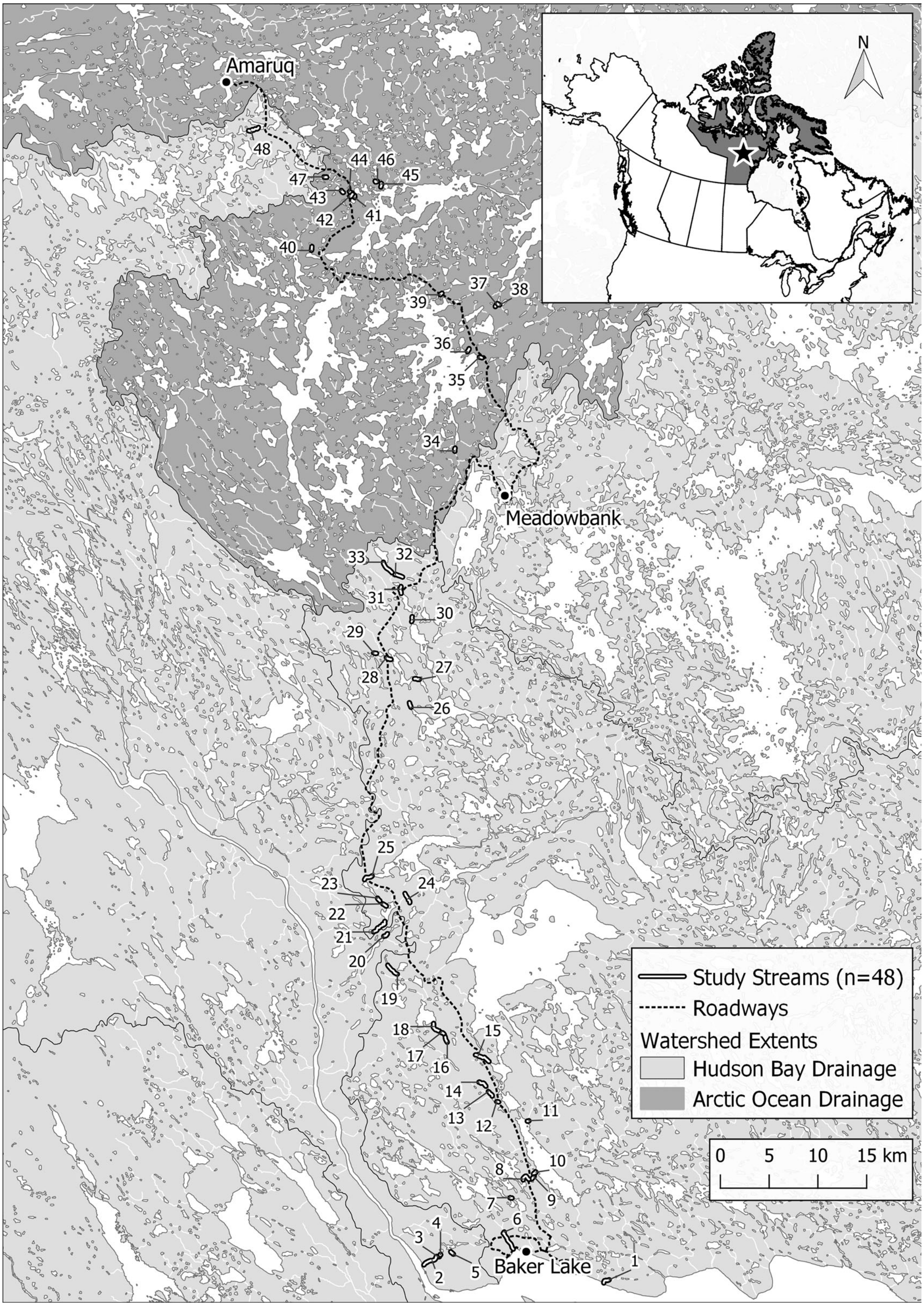
Networks of connected lakes and streams typically cover more than 20% of the Barrenlands (see Jones et al., 2003a; Campbell et al., 2012), and the importance of considering how stream-lake connectivity influences abundance and distribution of fish species is becoming increasingly evident (e.g., Jones, 2010; Haynes et al., 2014; Laske et al., 2016; Pépino et al., 2017; Heim et al., 2019a). Water stored in lakes can stabilize the flow regime of outlet streams (Dorava & Milner, 2000; Jones, 2010), with larger upstream lakes providing a source of water that may sustain flow throughout the summer (Jones et al., 2003a; Jones, 2010). Nearly all streams in the Barrenlands originate as lake outlets (Jones et al., 2003a), and as such the position of streams within Barrenland chain-lake systems determines the potential for upstream lakes to act as stable and moderating sources of flow, which could in turn influence habitat suitability for YOY Arctic grayling.

The objective of the study was to relate occupancy of YOY Arctic grayling to a range of variables that represent both instream and landscape-level conditions of streams near the Hamlet of Baker Lake, in the Kivalliq region of Nunavut. Using a single-season, spatially replicated occupancy modelling approach, we aimed to identify variables that were best associated with occupancy of YOY Arctic grayling. The overarching goal of this work is to generate a more comprehensive understanding of the distribution of Arctic grayling in Barrenland streams.

Methods

Study area

Located within the vast, remote ecoregion of the Wager Bay Plateau Barrenland tundra, the study area (approximately 1,400 km^2), extends north from the Hamlet of Baker Lake, Nunavut (64.3176° N, 96.0220° W) along a 175 km all-weather access road that services two gold mines, Meadowbank and Amaruq (Fig. 1). Access to this region is by air or sea only; there are no road connections other than between the hamlet and two mine sites located north of the hamlet. The study region is characterized by long, cold, dry winters (− 31.3°C daily average temperature, 6.2 mm of precipitation in January), cool summers (11.6°C daily average temperature in July), and relatively wet autumns (50.2 mm and 48.7 mm of precipitation in August and September, respectively) (Environment and Climate Change Canada, 2018). Study streams were limited to those that were accessible by foot (to a maximum distance of approximately 5 km) from either the all-weather access road or roads within the Hamlet of Baker Lake. Study streams were located within three watersheds: two watersheds are within the Hudson Bay drainage basin, and one is located within the Arctic Ocean drainage basin (Fig. 1). Arctic grayling, lake trout [*Salvelinus namaycush* (Walbaum, 1792)], Arctic char [*Salvelinus alpinus* (Linnaeus, 1758)], round whitefish [*Prosopium cylindraceum* (Pennant, 1784)], cisco [*Coregonus artedii* (Lesueur, 1818)], burbot [*Lota lota* (Linnaeus, 1758)], ninespine stickleback [*Pungitius pungitius* (Linnaeus, 1758)], and slimy sculpin [*Cottus cognatus* (Richardson, 1836)] are present within the study area; however, species assemblages vary among lake/chain-lake complexes (C. Portt and Associates, 2018; J. Ellenor, unpublished data). Robust data on the use of seasonally available stream habitat are lacking. Where present, YOY Arctic grayling are the dominant species within streams, with occasional presence of ninespine stickleback, slimy sculpin, and juvenile salmonids (including grayling) (Cumberland Resources Ltd., 2005; J. Ellenor, unpublished data).


Amaruq
Meadowbank
Baker Lake
N
Study Streams (n=48)
Roadways
Watershed Extents
Hudson Bay Drainage
Arctic Ocean Drainage
0 5 10 15 km
1
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◀**Fig. 1** Map of the study area, with watersheds delineated. The 48 study streams (identified numerically) were selected randomly from 109 candidate streams that were accessible by foot (within 5 km) from all-weather roads. In the inset map, the territory of Nunavut is shaded in grey, and the star indicates the approximate location of the hamlet of Baker Lake, Nunavut, Canada and the mine sites of Meadowbank and Amaruq

Ecological land classification data exist for the region (Campbell et al., 2012). The twelve land classes present within the study area are defined by moisture and substrate, and range from moist, organic, graminoid tundra to dry, lichen-rock complexes (Fig. 2a). Logistical constraints on field sampling limited replication within land classes. Therefore, the twelve land classes were reduced to two land classes: (1) upland; and, (2) lowland (Fig. 2b). The 'lowland' land class includes poorly drained substrate dominated by organic materials, whereas the 'upland' land class includes well-drained inorganic substrates, such as gravel, boulder, and bedrock (Fig. S1).

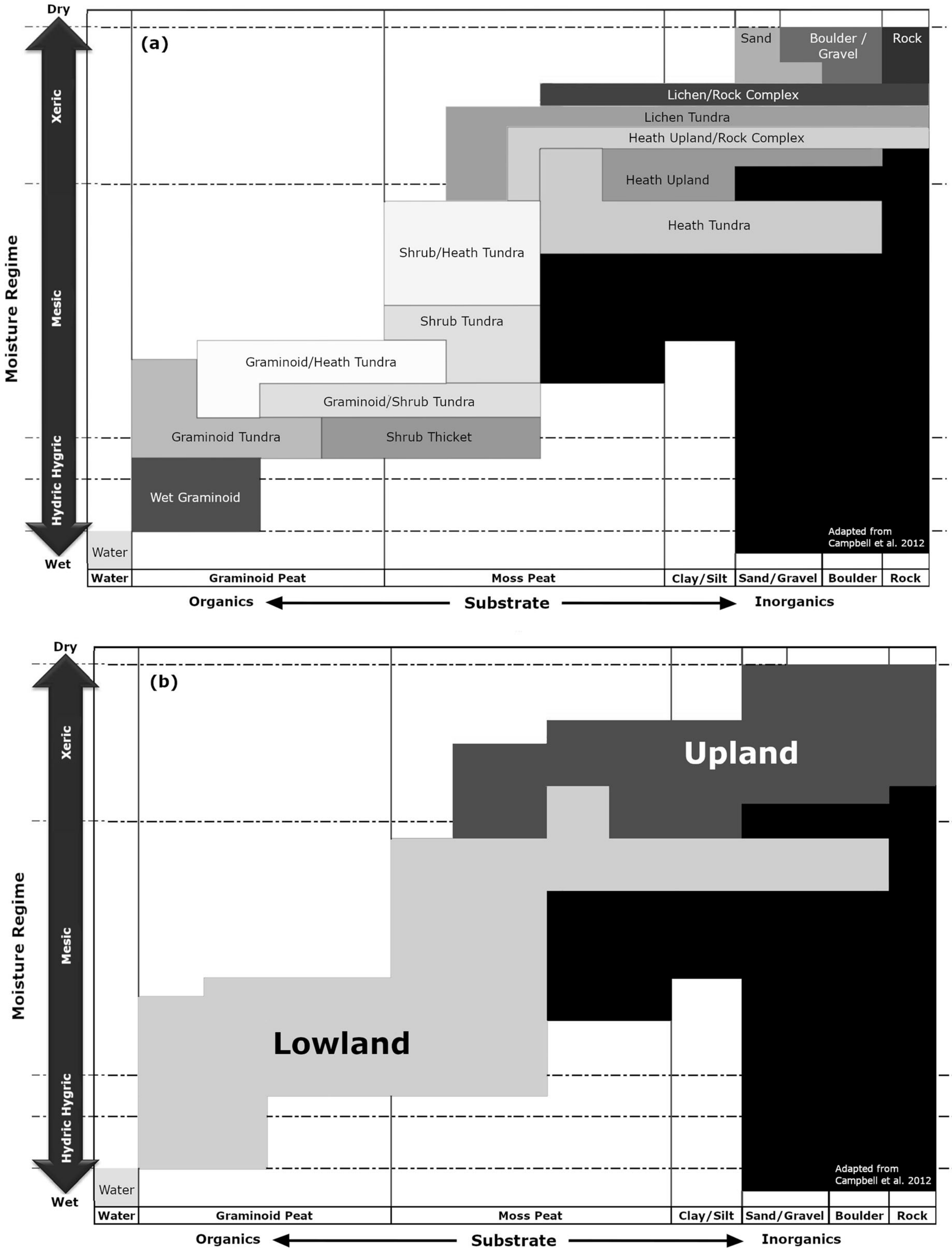
General study design

A spatially replicated, single-season occupancy design was implemented to assess the probability that study streams were occupied by YOY Arctic grayling during the 2019 summer rearing period. Forty-eight streams were randomly selected from one-hundred and nine candidate streams within the study area. Candidate streams were identified using watershed shapefiles (Natural Resources Canada, 2016) and satellite imagery [either publicly available (Google Earth, 2019a, b, c) or supplied by Agnico Eagle Mines Ltd.]. Study streams ranged in length from 158 m to 2,268 m, with a median length of 461 m. A sample site was randomly selected within each study stream. Sample sites were defined as five sequential 30 m surveys (spatial replicates), resulting in a total assessed length of 150 m per site (and therefore per stream). For each spatial replicate, presence or absence of YOY Arctic grayling was assessed and covariate data (e.g., habitat, sampling conditions) were collected.

Presence or absence of YOY Arctic grayling was assessed using streamside visual surveys, which have been shown to be an effective and efficient technique in Barrenland streams (Baker et al., 2017). False detections of YOY Arctic grayling during visual surveys were unlikely, as Arctic grayling is the only salmonid present within the study area that spawns in the spring, and the only salmonid known to spawn and rear in Barrenland streams. YOY Arctic grayling also occupy a unique size class relative to other juvenile salmonids. They are also distinguishable from small-bodied fish species, such as ninespine stickleback and slimy sculpin, based on their size, body shape, and behaviour. Prior to the onset of the formal study, trial visual surveys of YOY Arctic grayling in study area streams was followed by capture of individuals to confirm identification, and revealed consistent positive identification of YOY Arctic grayling.

Surveys were completed from July 16 to August 7, 2019. Survey dates were selected based on the observed timing of spawning, egg incubation, and YOY rearing in streams within the study area during summer 2018 (J. Ellenor, unpublished data). Consistent with the assumption of closure in occupancy modeling, the survey dates also reflect a period when YOY Arctic grayling have previously been observed rearing in Barrenland streams (Jones et al., 2003a; Artym, 2016), and several weeks in advance of migration to overwintering lakes, which typically occurs just prior to freeze-up (Jones et al., 2003b; Driedger et al., 2011).

During visual presence/absence surveys, two surveyors started on opposite ends of the most downstream replicate of a site. Surveyors walked towards each other along the stream bank while visually searching for YOY Arctic grayling. There were no restrictions placed on search method, and each team member was free to move about the replicate as they deemed fit. This included potentially entering the stream, a method that was typically only employed when stream width prevented effective visual surveys of the entire channel from the bank. After 3 min had elapsed, surveyors paused to confirm if either had a positive detection. If both had observed YOY Arctic grayling, the survey was deemed complete. If only one observer, or neither observer, had observed YOY, the survey continued until 8 min had elapsed, at which point the survey was considered complete, regardless of detection. A maximum survey duration of 8 min provided sufficient time to effectively search a 30 m segment of stream. The process was then repeated at adjacent upstream replicates. The same two team members conducted all surveys in 2019.


Dry
(a)
Sand
Boulder / Gravel
Rock
Lichen/Rock Complex
Lichen Tundra
Heath Upland/Rock Complex
Heath Upland
Heath Tundra
Shrub/Heath Tundra
Shrub Tundra
Graminoid/Heath Tundra
Graminoid/Shrub Tundra
Graminoid Tundra
Shrub Thicket
Wet Graminoid
Water
Wet
Moisture Regime
Xeric
Mesic
Hygric
Hydric
Adapted from Campbell et al. 2012
Water
Graminoid Peat
Moss Peat
Clay/Silt
Sand/Gravel
Boulder
Rock
Organics
Substrate
Inorganics
Dry
(b)
Upland
Lowland
Water
Wet
Moisture Regime
Xeric
Mesic
Hygric
Hydric
Adapted from Campbell et al. 2012
Water
Graminoid Peat
Moss Peat
Clay/Silt
Sand/Gravel
Boulder
Rock
Organics
Substrate
Inorganics

◀**Fig. 2** Moisture regime and substrate characteristics for **a** twelve ecological land cover classes identified in Campbell et al. (2012) and **b** simplified lowland and upland land cover classes. The delineation of lowland and upland classes for this study was based on moisture. Moist vegetation classes (i.e., mesic, hygric, and hydric) were classified as lowland, whereas dry vegetation classes (i.e., xeric) were classified as upland. Images adapted with permission

The probability of detecting Arctic grayling in a replicate, given presence, was anticipated to be influenced by instream (e.g., water depth, substrate, stream width) and other environmental (e.g., percentage of sunlight/cloud cover during the survey) variables. Similarly, stream habitat and/or landscape level variables were expected to influence the probability of occupancy; the relationship between these variables and probability of occupancy was the primary focus of this study. To account for heterogeneity in probability of detection and occupancy, covariate data were collected and incorporated into candidate models (Table 1). Consistent with established approaches (e.g., MacKenzie et al., 2018), variables thought only to influence probability of detection were collected at each spatial replicate (site), whereas variables thought to influence the probability of occupancy were collected at each stream. Variables that were thought to influence both probability of detection and probability of occupancy that are likely to vary by replicate (e.g., water velocity) were collected at the scale of 30 m replicates to model probability of detection, and then averaged (arithmetic mean) across all replicates to model probability of occupancy.

Depth and velocity measurements were collected using a topset rod mounted to a HACH FH950 handheld flowmeter (HACH, Loveland, CO). Readings were taken at five points per 30 m replicate along a transect that ran perpendicular to the stream flow. Transect and measurement locations were selected to capture representative depth/velocity conditions. This

Table 1 Summary of covariates, including collection methods, that were collected to account for potential heterogeneity in probability of detection (30 m replicate; site) and probability of occupancy (stream)

Probability affected	Collection scale	Covariate	Collection method
Detection	30 m Replicate	Survey date	–
		Time of day	–
		Survey technician	–
		Cloud cover	Visual estimate (%)
		Precipitation	Type/intensity category
Detection and occupancy	30 m Replicate	Depth	Wading rod (m)
		Velocity	Flow meter (m/s)
		Substrate	Estimate (%, per size class)
		Instream vegetation	Estimate (%)
		Overhanging vegetation	Estimate (%)
		Undercut bank	Estimate (%)
		Wetted width	Tape measure/range finder (m)
		Number of channels/braids	Count
		Slope	Inclinometer (%)
	Stream	Discharge	Flow meter (m^3/s)
		Stream temperature	Temperature logger (°C)
		pH	In situ meter
		Dissolved oxygen	In situ meter (mg/L, % saturation)
		Specific conductivity	In situ meter (μS/cm)
		Land classification	GIS
		Cumulative upstream lake area	GIS

transect was also used to measure total stream width (wetted edge to wetted edge, while removing the width of any mid-channel bars). Locations selected for discharge measurements had laminar flow that was perpendicular to the streambank. Discharge readings followed methods outlined by the Water Survey of Canada (Lane, 1999).

Water temperature data were collected at each stream using a single TidbiT® V2 temperature logger set to record at 10-min intervals (Onset Computer Corporation, Bourne, MA). Each temperature logger was placed in a solar shield, attached to a weight, and placed at the bottom of the stream. Temperature data are available for all streams from June 27, 2019 to August 29, 2019. Summary statistics were calculated for each stream, including daily mean, mean minimum, mean maximum, and mean daily coefficient of variation (CV), as well as accumulated thermal units (ATU). Temperature data preparation and analysis were completed in R (R Core Team, 2019).

In situ water quality data were collected using calibrated hand-held meters. Dissolved oxygen (mg/L and % saturation) data were collected using an OxyGuard Handy Polaris (OxyGaurd International A/S, Farum, Denmark). Specific conductivity (µS/cm) and pH data were collected using a YSI Pro Plus (YSI Incorporated, Yellow Springs, OH). Meters were allowed sufficient time to equilibrate in the stream prior to recording measurements.

Substrate was estimated visually, and recorded as relative percentages of streambed material. Streambed material was categorized as organic material, or size class of inorganic material [bedrock, boulder, cobble, etc.; (Bain et al., 1985)]. In-stream vegetation was estimated visually as the percentage of in-stream cover provided by emergent/submerged vegetation, whereas overhanging vegetation was estimated visually as the percentage of the streambank with overhanging vegetation. Stream slope was calculated using an inclinometer along a straight portion of stream that had representative slope.

Ecological land classification data for the study area were provided as a raster dataset (25 m × 25 m resolution) by the Nunavut Department of Environment and Caslys Consulting (Campbell et al., 2012), imported into QGIS (QGIS Development Team, 2020), and simplified into two classes (Fig. 2). Study streams were digitized as linear segments, and a 10 m buffer (total width of 20 m) was applied to each stream. Percentages of upland and lowland land classes within the buffer areas were then calculated for each stream.

Lake polygon and watercourse data used to calculate the surface area of contributing upstream lakes were obtained from the National Hydro Network (Natural Resources Canada, 2016). Surface areas of lakes within the study region were calculated using QGIS (QGIS Development Team, 2020). The contributing upstream lake surface area for each stream was calculated as the sum of all upstream lake surface areas (i.e., surface area of all upstream lakes that are connected by a watercourse, as identified by the National Hydrology Network shapefile).

Statistical analysis

R version 3.6.2 (R Core Team, 2019) was used for data visualization using packages ggplot2 (Wickham, 2016), see (Lüdecke et al., 2020), and patchwork (Lin Pederson, 2020). Construction of occupancy models was achieved using the RPresence package (MacKenzie & Hines, 2019). Prior to the construction of occupancy models that incorporated covariates, a comparison was made between static single-season and single-season correlated detection null models as recommended by MacKenzie et al. (2018). This comparison assessed the need to account for autocorrelated data, which could occur if the presence/absence of YOY in a downstream replicate was influenced by the presence/absence of YOY in the replicate immediately upstream.

The construction of single-season occupancy models was divided into two components: (1) modeling variables that affected the probability that YOY were present at a site (stream); and (2) modeling variables that affected the probability that YOY were detected at a 30 m replicate. While initially modeling for stream occupancy, the probability of detection was held constant at $p(\cdot)$. Covariates of probability of detection were then incorporated into top candidate occupancy models.

Due to the small number of study streams (n = 48), a maximum of three occupancy covariates were included in any one a priori model to avoid overparameterization (Anderson, 2008). Data transformations for continuous occupancy covariates were assessed prior to model construction. A transformation was applied if the covariate clearly had a large influence on the probability of occupancy within a small range of its total observed range, and a reduced influence for the remainder of the observed range (see MacKenzie et al., 2018). Continuous covariates in detection and occupancy datasets were also standardized (z-score) prior to model construction and assessed for collinearity using Pearson correlation coefficients (pair-wise comparisons). Covariates with a correlation coefficient with an absolute value greater than 0.5 were not included in the same model.

Candidate models were assessed using Akaike's Information Criterion, incorporating an additional bias correction term (AICc) for small sample sizes (Anderson, 2008). Following Baker et al. (2017), the number of streams ($n = 48$) was selected as the 'effective' sample size for the AICc correction term. Constructed models were compared based on their relative difference in AICc values (ΔAICc), model weights, and evidence ratios (Anderson, 2008). Model fit was assessed using the methods outlined in MacKenzie & Bailey (2004). Pearson's chi-squared (χ^2) test statistics for observed and parametric bootstrapped data were compared to determine the probability of obtaining the observed detection history at each stream, assuming the model was correct (MacKenzie et al., 2018). Additionally, an independent test data set of seven streams located along the all-weather access road from Meadowbank to Amaruq (Fig. 1) were used to assess model fit. These streams were electrofished between 25 June and 02 September, 2014–2015, prior to road construction and prior to design and implementation of this study (C. Portt and Associates, 2015).

Results

Young-of-year Arctic grayling were detected in 32 of 48 surveyed streams, resulting in a naïve occupancy estimate of 0.67 (naïve occupancy assumes perfect detection). In the 32 streams occupied by YOY, they were detected in 130 of 160 replicates, resulting in an overall detection probability of 0.81. YOY were detected in all five replicates (i.e., perfect detection) in twenty of the thirty-two occupied streams (63.5%). They were detected in four of five replicates in two streams (6.3%), in three of five replicates in four streams (12.5%), in two of five replicates in four streams (12.5%), and in one of five replicates in two streams (6.3%) (Fig. S2).

Occupancy

Type of occupancy model

A correlated detection null model was run to assess the need to account for autocorrelated data (i.e., the presence/absence of YOY in a downstream replicate was influenced by the presence/absence of YOY in the replicate immediately upstream). The correlated detection null model failed to converge. Lack of convergence could mean that sequential spatial replicates were not correlated, or result from other factors, including: (i) an insufficient number of sites or replicates to accurately model autocorrelation; and/or, (ii) an overall high detection rate, and a low number of sites with imperfect detection. In a similar study of YOY Arctic grayling occupancy in Barrenland streams, Baker et al. (2017) found clear evidence of spatial dependency with fewer sites and replicates (9 streams, 67 replicates), and a lower, more variable detection rate. In this study, the start location of a site was randomly selected in each stream, and the mean percentage of total stream length that was surveyed was 34% (range of 7–96%). A high overall detection probability (0.81) and high percentage of sites with perfect detection (63.5%), suggests that YOY were present throughout the occupied streams. Further, detection histories for the limited number of streams with imperfect detection showed no clear upstream to downstream relationship with presence/absence (Fig. S2). Given that occupancy was assessed at the stream level, it is anticipated that randomly selected replicates within a stream would produce similar results. Because the correlated detection model did not converge, all candidate models were constructed using the static single-season occupancy equation.

Occupancy covariates

Investigative plots revealed that several variables potentially influenced the probability of a stream being occupied by YOY Arctic grayling (Fig. 3): substrate, slope, water temperature, discharge, lowland cover, and contributing upstream lake area.

Most study streams were dominated by inorganic substrates, primarily boulder and/or cobble. No

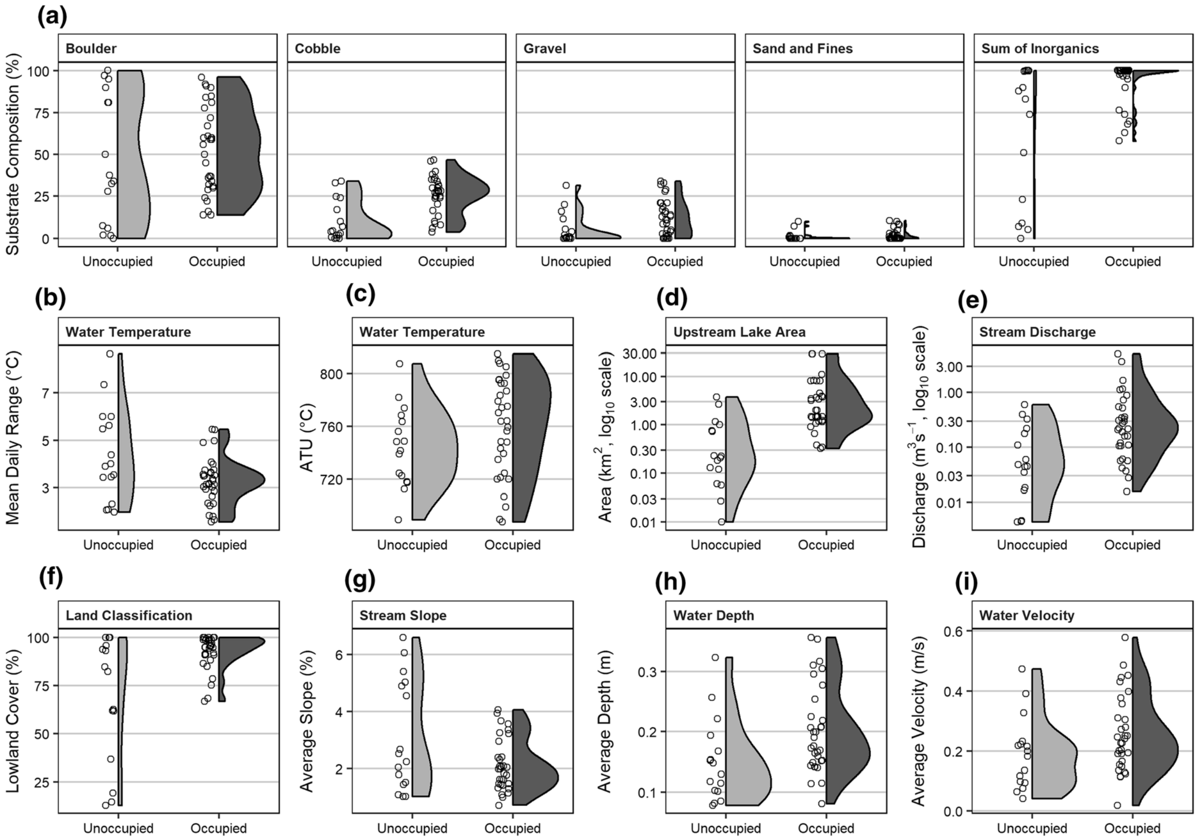


Fig. 3 Relationships between stream occupancy of young-of-year Arctic grayling and select stream- and landscape-level covariates. Individual study streams are represented by open circles. Distribution curves for each covariate for occupied and unoccupied streams are kernel density estimations. Data were collected near Baker Lake, Nunavut, Canada in 2019

individual size class (e.g., boulder, cobble, or gravel) of inorganic substrate was related to stream occupancy (Fig. 3a). The sum of all sizes classes of inorganic substrate [i.e., % inorganic substrate (Fig. 3a)] was, however, positively and non-linearly related to occupancy. Increases in % inorganic substrate had a greater effect on the probability of occupancy when % inorganic substrate was low, and a lesser effect when % inorganic substrate was high (Fig. 3a).

The percentage of inorganic substrate was correlated with various water temperature covariates, suggesting that water temperature may also influence stream occupancy. There was a strong, negative correlation between % inorganic substrate and mean daily temperature range ($r = -0.74$; Fig. 3b) and mean daily max temperature (r = − 0.65) (Table S1). Other temperature metrics, such as ATU, provided little explanation for the observed distribution of YOY among streams (Fig. 3c).

The cumulative surface area of lakes upstream varied considerably among study streams (0.01 km^2–26.5 km^2). YOY were not detected in any of the ten streams with upstream contributing lake area less than 0.3 km^2 (Fig. 3d). The likelihood that a stream was occupied increased considerably when upstream contributing lake area exceeded $\sim$ 0.3 km^2. Contributing upstream lake area was positively and significantly correlated with stream discharge ($r = 0.87$, Table S1, Fig. S3). The pattern of stream occupancy for upstream lake area and discharge were nearly identical (Fig. 3d, e), suggesting that upstream lakes provide an important source of water for streams. Although not strongly correlated, many of the streams with low contributions of upstream lake area also had high % organic substrate (r = − 0.28, Table S1), and the six streams with the highest % organic substrate all had contributing upstream lake areas < 0.33 km^2.

The dominant land cover for most study streams was lowland (i.e., moist, organic substrate). Of the 41 streams with > 65% lowland land cover, 32 (78%) contained YOY. Streams with < 65% lowland land cover (≥ 35% upland land cover), did not contain YOY grayling (Fig. 3f). The relationship between YOY grayling occupancy and land classification was similar to the relationship between YOY grayling occupancy and substrate—small increases in % lowland land cover had a greater effect on the probability of occupancy when % lowland land cover was low to moderate (i.e., < 65%) (Fig. 3f).

The average slope of surveyed streams varied from 0.7% to 6.6%. YOY Arctic grayling were not detected in the six streams where average slopes exceeded 4.1% (Fig. 3g), suggesting that as stream slope increases, the probability that the stream is occupied decreases. YOY grayling were found within streams with a range of average depths, and velocities (Fig. 3h, i, Table S2), and these variables did not appear to be strong predictors of occupancy.

Occupancy model results

Covariates included in candidate models for occupancy were limited to five variables: % lowland, % inorganic substrate, slope, mean daily water temperature range, and upstream lake area. A comparison of the ΔAICc values shows a clear top model (Table 2). Land classification (% lowland) and contributing upstream lake area were the best predictors of occupancy of YOY Arctic grayling in streams. Regression coefficients (on the logit scale) show the magnitude and direction of the covariate on the probability of occupancy, $(\widehat{\psi})$ (MacKenzie et al., 2018). For the top model, this can be written as:

$$logit(\widehat{\psi}) = \beta_0 + \beta_1 \times \sqrt{Lowland\%} + \beta_2 \times log_{10}(UpstreamLakeArea)$$

where β-coefficients (standard errors) are, β_0 = 2.02 (0.82), β_1 = 1.97 (0.74), and β_2 = 4.10 (1.44).

Estimates of β-coefficients indicated that increases in lowland land cover and increases in contributing upstream lake surface area both increased the probability that a stream was occupied by YOY Arctic grayling. Streams with larger contributing upstream lake area and more lowland cover were more likely to be occupied. Probability of occupancy was calculated for % lowland values ranging from 0% to 100%, while contributing upstream lake area was held constant at the median observed value (1.43 km^2) (Fig. 4a). Streams surrounded exclusively by lowland land cover had a high likelihood of containing YOY grayling. The probably of occupancy decreased as lowland land cover decreased. Confidence intervals (95% CI) around the probability of occupancy, calculated using the delta method (MacKenzie et al., 2018), indicated higher confidence in predicting occupancy at high percentages of lowland land cover (i.e., > 85%) (Fig. 4a). When examining the relationship between contributing upstream lake area and occupancy [while holding % lowland land cover constant at the median study stream value (94.5%)], the probability that a stream was occupied increased sharply from 0 to 0.8 as contributing upstream lake area increased from 0 km^2 to 1 km^2 (Fig. 4b). As contributing upstream lake area increased beyond 1 km^2, the 95% confidence interval narrowed, suggesting increasing confidence that a stream was occupied as upstream lake surface area increased.

Occupancy was highest when contributing upstream lake area and percent lowland land cover were both high (Fig. 5a). Some combinations of percent lowland land cover and contributing upstream lake area were not represented within the study. Given the random sampling design, it is likely these conditions are rare within the study area.

When the 16 unoccupied streams were examined, it was evident that absence of YOY Arctic grayling in 10 of these streams was explained by insufficient contributing upstream lake area (Fig. 5b). In four of the unoccupied streams, insufficient contributing upstream lake area did not appear to be an explanation. These four streams had the lowest percentages of lowland land cover of any of the study streams. These results suggest that streams located in landscapes with more uplands require more upstream lake area to be suitable for YOY. Absence of YOY Arctic grayling in two streams was not explained by either land cover or contributing upstream lake area (Fig. 5b).

The model predicted both presence and absence of YOY Arctic grayling with confidence (i.e., small confidence interval range) under certain combinations of upstream lake area and land cover (Fig. 5c). There was high confidence that streams with low % lowland land cover and small contributing upstream lake areas were unoccupied. Similarly, there was high confidence

Table 2 Summary of candidate occupancy models for Arctic grayling young-of-year in Barrenland streams

Model	ΔAICc	− 2*l*	ω	Coefficient estimates (± standard error)				
				$\sqrt{\text{Lowland}}$	log(UpstreamLakeArea)	$\sqrt{\text{Inorganic}}$	Slope	Mean daily temperature range
$\psi\left(\sqrt{Lowland} + \log(Upstream;Lake;Area)\right)$	0.00	158.74	0.98	1.97 (0.74)	4.10 (1.44)	–	–	–
$\psi\left(\sqrt{Lowland} + \sqrt{Inorganic} + Slope\right)$	8.56	164.40	0.01	2.14 (0.98)	–	2.99 (1.38)	− 1.29 (0.61)	–
$\psi\left(\sqrt{Lowland} + \sqrt{Inorganic}\right)$	11.48	170.22	0	2.17 (0.88)	–	2.38 (1.08)	–	–
$\psi(\log(UpstreamLakeArea))$	14.09	175.58	0	–	2.35 (0.70)	–	–	–
$\psi\left(\sqrt{Lowland} + Slope + MeanDailyTemperatureRange\right)$	14.40	170.25	0	1.89 (0.67)	–	–	− 0.85 (0.45)	− 1.64 (0.60)
$\psi\left(\sqrt{Lowland} + MeanDailyTemperatureRange\right)$	15.80	174.54	0	2.04 (0.73)	–	–	–	− 1.72 (0.62)
$\psi(\sqrt{Inorganic} + Slope)$	23.57	182.30	0	–	–	–	–	–
$\psi\left(\sqrt{Lowland} + Slope\right)$	24.18	182.92	0	1.55 (0.72)	–	–	− 0.84 (0.39)	–
$\psi(\sqrt{Inorganic})$	26.64	188.13	0	–	–	1.45 (0.64)	–	–
$\psi\left(\sqrt{Lowland}\right)$	26.68	188.17	0	1.51 (0.66)	–	–	–	–
$\psi(Slope + MeanDailyTemperatureRange)$	30.25	188.99	0	–	–	–	− 0.73 (0.35)	− 0.82 (0.37)
$\psi(MeanDailyTemperatureRange)$	32.34	193.83	0	–	–	–	–	− 0.82 (0.36)
$\psi(Slope)$	33.29	194.78	0	–	–	–	− 0.72 (0.33)	–
$\psi(\cdot)$	35.87	199.98	0	–	–	–	–	–
$\psi(\cdot)\theta(\cdot)\theta'(\cdot)p(\cdot)$*	38.24	202.85	0	–	–	–	–	–
$\psi(\cdot)p(\cdot)$	44.24	215.52	0	-	–	–	–	–

ΔAICc, difference in AICc value between a particular model compared to the top ranked model, − 2*l*, twice the negative log-likelihood value, ω AIC model weight

Detection probability was modeled as p (depth × velocity) for all models, with the exception of the correlated detection null model, $\theta(\cdot)\theta'(\cdot)p(\cdot)$, and the static null model, p(·)

*The correlated detection model failed to converge mathematically and was removed from consideration

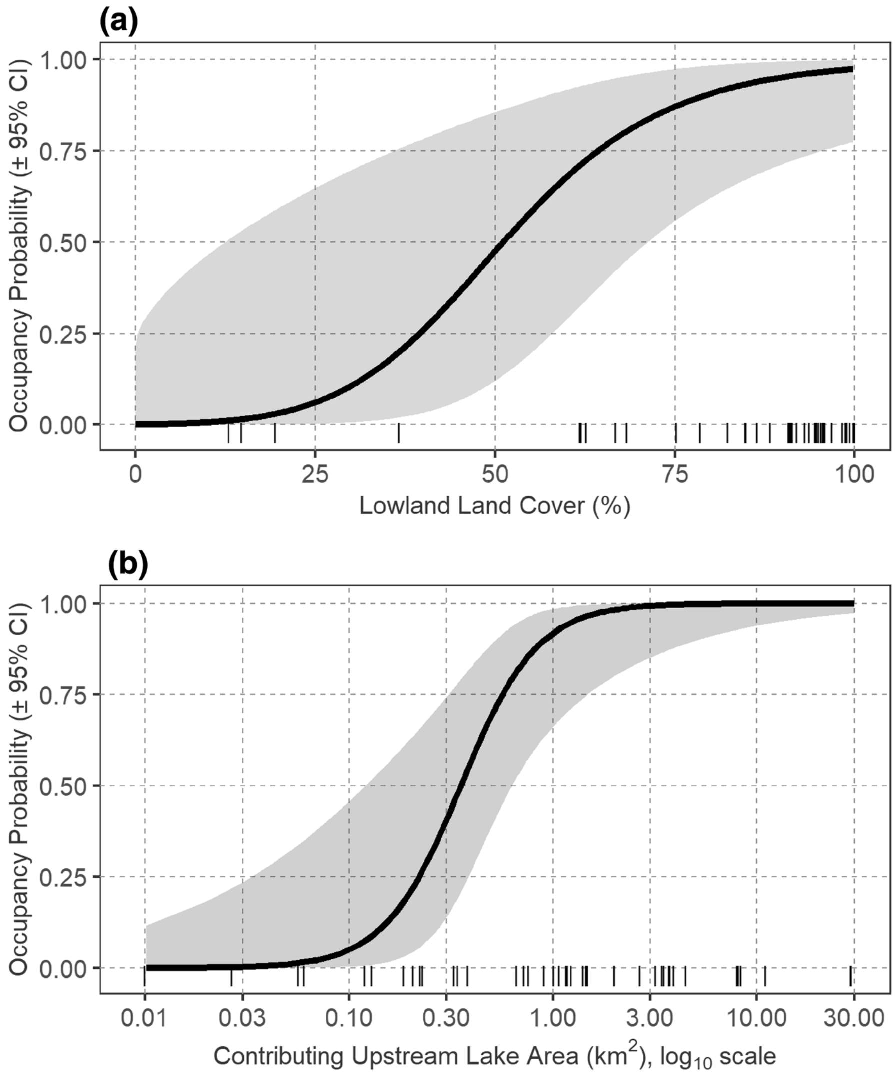
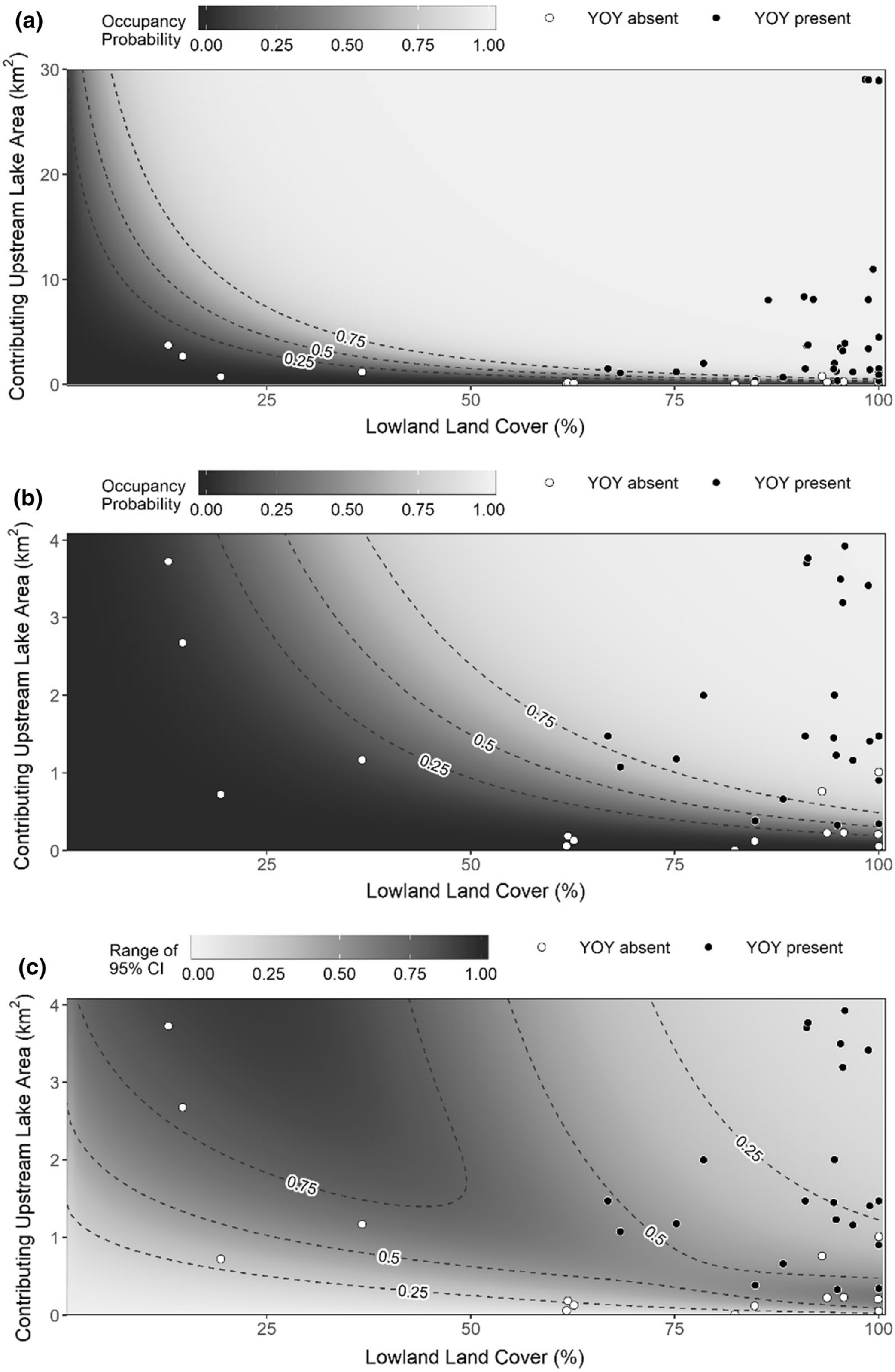


Fig. 4 Relationship between **a** probability of occupancy of young of year Arctic grayling and % lowland land cover at the median value of contributing upstream lake (1.43 km^2); and, **b** probability of occupancy and contributing upstream lake area at the median value of % lowland land cover (94.5%). Vertical tick marks along the x-axis are sampled stream values used to construct the model. Data were collected near Baker Lake, Nunavut, Canada in 2019

that streams with high % lowland land cover and large contributing upstream lake areas were occupied (Fig. 5c). Uncertainty was greatest where the two covariates had an opposing influence on occupancy. For instance, if a stream with a low percentage of lowland land cover also had a large contributing upstream lake area, there was increased uncertainty in the model result (Fig. 5c). This was particularly true for conditions that were under-sampled (and/or less common) in the study area.

Detection

Each of the covariates for probability of detection was individually considered for inclusion in candidate models. A summary of the observed range of each variable, and the ranges of covariates for replicates where YOY Arctic grayling were and were not detected are provided in Table S3. Depth and velocity were the only two detection variables with a lower AICc score than the null model, indicating that depth and velocity provided some explanation for imperfect detection (Table 3). The highest ranked model included an interaction between depth and velocity, but there was also support for an additive model (Table 3). An examination of regression coefficients (Table 3) revealed that increases in depth and/or velocity decreased the likelihood of YOY being detected, which is intuitive given that surveys were conducted visually and fish are more difficult to see at


(a)
Occupancy Probability
0.00 0.25 0.50 0.75 1.00
YOY absent
YOY present
Contributing Upstream Lake Area (km^2)
0 10 20 30
0.75
0.5
0.25
25 50 75 100
Lowland Land Cover (%)
(b)
Occupancy Probability
0.00 0.25 0.50 0.75 1.00
YOY absent
YOY present
Contributing Upstream Lake Area (km^2)
0 1 2 3 4
0.75
0.5
0.25
25 50 75 100
Lowland Land Cover (%)
(c)
Range of 95% CI
0.00 0.25 0.50 0.75 1.00
YOY absent
YOY present
Contributing Upstream Lake Area (km^2)
0 1 2 3 4
0.75
0.5
0.25
0.5
0.25
25 50 75 100
Lowland Land Cover (%)

◀**Fig. 5** Bivariate plots of contributing upstream lake area and % lowland land cover showing **a** probability of occupancy of young of year Arctic grayling for the full range of stream conditions observed, **b** estimated occupancy of YOY for the range of contributing upstream lake area where probability of occupancy transitioned from low to high (note different Y axis compared to **a**), and **c** the range of 95% confidence intervals for the occupancy estimate, calculated as the upper limit minus the lower limit. The contour lines identify occupancy probabilities (**a** and **b**) and confidence interval ranges (**c**) of 0.25, 0.50, and 0.75. Combined, these variables explained the occupancy results for 46 of the 48 streams included in the model. The 95% confidence interval ranges show that the model predicted both presence and absence with confidence (i.e., CI < 0.25), under certain combinations of upstream lake area and land cover. Data were collected near Baker Lake, Nunavut, Canada in 2019

greater depths or with greater disturbance (higher velocity). The interaction term suggests that detection probability remained high in deep water with low velocity, or in shallow water with high velocity. However, detection probability decreased rapidly in deep, high velocity water.

Assessment of model fit

Occupancy

Model fit was evaluated using independent presence/absence data that were collected several years prior to the study, and from additional streams within the study area (C. Portt and Associates, 2015). Land classification and contributing upstream lake area were calculated for the seven streams in the test data set, and were used to estimate probability of occupancy. No Arctic grayling of any life stage were detected in the seven streams and the absence of YOY in these streams was well-predicted by the model (Fig. S4a); probability of occupancy was < 0.20 for six streams, whereas probability of occupancy was 0.66 for one stream. The estimated occupancy probability of 0.66 for the one unoccupied stream was associated with a large 95% CI (0.08–0.98; Fig. S4b).

Detection

A comparison of χ^2 test statistics between observed and parametric bootstrapped data yielded a $\widehat{c}$ value of 3.4, suggesting the model is overdispersed. Overdispersion can reflect non-independent observations (e.g., detection in replicate B is dependent on detection in replicate A) or structural inadequacies, such as unmodeled heterogeneity in detection. A model structure that included spatial dependency failed to converge (see above). We suggest that unmodeled heterogeneity in detection probability was due to relative differences in abundance of YOY among streams, which in turn affected detection probabilities. If abundance was not correlated with any detection covariates that were collected, then heterogeneity remains unmodeled. A comparison of the observation rate (number of YOY observed per minute) among replicates during presence/absence surveys at each stream suggests that detection efficiency is related to

Table 3 Summary of detection models for visual surveys of Arctic grayling young-of-year in Barrenland streams

Model	ΔAICc	− 2*l*	ω	Coefficient estimates (± standard error)		
				Depth	Velocity	Depth × velocity
p (Depth × velocity)	0.00	158.74	0.43	− 0.42 (0.22)	− 0.32 (0.22)	− 0.31 (0.20)
p (Depth + velocity)	0.37	161.85	0.36	− 0.42 (0.22)	− 0.44 (0.19)	–
p (Velocity)	2.75	166.86	0.11	–	− 0.51 (0.19)	–
p (Depth)	3.02	167.13	0.09	− 0.48 (0.18)	–	–
p (·)	7.68	174.28	0.01	–	–	–

To allow for a direct comparison, the same model for occupancy probability was used for all candidate detection models

ΔAICc, difference in AICc value between a particular model compared to the top ranked model; − 2*l*, twice the negative log-likelihood value; ω, AIC model weight

Occupancy probability was modeled as $\psi\left(\sqrt{Lowland\%} + \log(UpstreamLakeArea)\right)$ for all models, with the exception of the null, Ψ(·)

abundance. Observation rate within a replicate (where YOY were detected) was lower in streams with imperfect detection, and decreased as detection efficiency decreased (Fig. S5); high observation rates (up to 7.33 YOY/minute) occurred at streams with perfect detection, and low observation rates (as low as 0.13 YOY/minute) occurred at streams with imperfect detection. A higher observation rate is likely the result of an increased number of YOY within the stream, suggesting that relative differences in abundance among streams, which are unaccounted for in the model, led to higher than expected variance (i.e., overdispersion) (Royle & Nichols, 2003). Since overdispersion was not attributed to non-independent observations, a correction to the AIC scores (QAIC) was not applied (as per MacKenzie et al., 2018).

Discussion

Occupancy

The suitability of Barrenland streams for YOY Arctic grayling was strongly influenced by the surrounding landscape. Two landscape-level variables, land classification (upland vs. lowland) and contributing upstream lake area, were better predictors of YOY grayling occupancy than any combination of the within-stream habitat variables that were collected. By considering how landscape-level variables affect stream habitat, particularly during the summer rearing period, critical habitat for YOY Arctic grayling in Barrenlands landscapes can be better understood and predicted. This will allow for more effective and efficient monitoring, mitigation, and conservation in this vast, remote, and understudied ecoregion.

Sixteen of 48 surveyed streams were unoccupied, and absence of Arctic grayling YOY in 10 of the unoccupied streams was explained by having fewer or smaller lakes upstream, providing less contribution to base flow. Headwater streams, and those that were located further upstream within a chain-lake system, had a lower probability of containing YOY Arctic grayling. Lakes are known to moderate and improve the reliability of source flow (Jones, 2010), and the degree to which an upstream catchment contributes to downstream flow is dependent on antecedent lake storage, rainfall, and evaporative losses (Baki et al., 2012; Baker et al., 2016). In a landscape where summer evaporation typically exceeds precipitation, an increase in the number and/or size of upstream lakes may increase the likelihood that streamflow and connectivity for migratory fishes will be sustained throughout the ice-free season. For YOY Arctic grayling, sustained flow is crucial, as habitat connectivity is required for migration to overwintering lakes prior to freeze-up (Jones et al., 2003a; Heim et al., 2016). The importance of stream connectivity for Arctic grayling distribution has also been noted in the Arctic Coastal Plains of Alaska, where a sustained stream connection during the open water season (rather than an ephemeral connection) is a strong predictor of Arctic grayling occupancy in lakes (Haynes et al., 2014; Laske et al., 2016). In the Barrenlands, Arctic grayling use of chain-lake habitat, particularly lakes with inconsistent connectivity, warrants investigation and may help to further explain YOY stream occupancy.

Further evidence of the influence of upstream lakes on stream flow was demonstrated by the significant and positive correlation between contributing upstream lake area and stream discharge (Pearson's r of 0.87). This suggests that upstream lakes contribute to maintaining baseflow in Barrenland streams in the study area throughout the open water season, and among years. Unoccupied streams with low contributing upstream lake area were likely unsuitable for YOY Arctic grayling due to insufficient discharge. Contributing upstream lake area may, in fact, be used as a reliable surrogate for discharge in Barrenlands landscapes, and allow for comparisons among streams when discharge measurements cannot be taken within a short temporal window. Stream discharge measurements for this study were collected under a wide range of weather conditions, including periods of dry weather followed by heavy rain events. These events, including one when 48 mm of rain fell in less than 72 h, influenced discharge and confounded comparisons among streams (Fig. S3). Incorporating contributing upstream lake area into models in place of discharge allowed for a comparison among streams that was more representative of longer-term hydrological conditions. Barrenland streams with reliable flow during the open water season, or a predictable, sustained discharge across years are more likely to be used by Arctic grayling (see Heim et al., 2019b). Given that Arctic grayling show strong site fidelity to spawning and summer feeding sites (Northcote, 1995;

Deegan et al., 1999; Buzby & Deegan, 2000), the absence of YOY in streams may be a result of an unpredictable base flow across years, which can be assessed more accurately in the Barrenlands by calculating upstream lake area rather than by collecting a single discharge measurement in a given year.

Streams with small contributing upstream lake area (and correlated lower discharge) had additional habitat features that were likely unsuitable for YOY Arctic grayling. Many of these small streams were dominated by organic substrates and instream vegetation, likely because there was insufficient flow to mobilize even fine substrates. The six streams with highest % organic substrate were a subset of the 10 streams where YOY absence was explained by low contributing upstream lake area. Arctic grayling prefer gravel for spawning (Stewart et al., 2007). High relative % organic material within streams that have small upstream lake area and low discharge may be unsuitable for spawning adults, leading to absence of YOY. Organic substrate was also highly correlated with several stream temperature metrics. Streams dominated by organic substrate had less stable temperature profiles, as daily temperature fluctuated up to 8°C, and maximum temperatures sometimes exceeded 20°C. This is likely because dark organic substrate absorbs more solar energy relative to the lighter coloured inorganic substrates. Data on the upper range of stream temperature used by YOY Arctic grayling is lacking (Stewart et al., 2007), although the thermal tolerance of YOY grayling has been found to exceed 24°C (LaPerriere & Carlson, 1973). Deegan et al. (1999) and Luecke & MacKinnon (2008) found that growth of YOY Arctic grayling in Alaskan streams was positively correlated with water temperature; however, the effects of large, daily water temperature fluctuations on YOY habitat suitability are unknown, and requires further study.

Although low contributing upstream lake area explained absence of YOY in 10 of 16 unoccupied streams, YOY Arctic grayling were absent in six streams that appeared to have sufficient streamflow. Four of six of these absences were explained by land classification. Most streams included in this study were situated within lowland-dominated landscapes; however, four study streams where YOY were absent had upland land cover that exceeded 50%. Since Barrenland streams are colluvial, upland streams are dominated by unconfined boulder channels with large interstitial spaces (Fig. S6). Reductions in flow and loss of surface connectivity in Barrenland streams over the course of the summer (Jones et al., 2003a) may be especially prevalent in upland landscapes, where interstitial spaces around boulders and unconfined channel structures promote subsurface flow at low discharges. Indeed, this was directly observed at several upland study streams in late summer (Fig. S6), and suggests that a larger contributing upstream lake area is required to maintain connectivity throughout summer for streams in upland-dominated landscapes. Power & Barton (1987) describe stream conditions in Ungava Bay, Quebec, where diffuse and subsurface flow through boulder-dominated streams prevented upstream migration of Arctic char, particularly in dry years. Reduced stream flow in the fall as a result of climate change is expected to affect connectivity of Arctic aquatic habitats, with particularly large effects on migratory fishes (Reist et al., 2006; Betts & Kane, 2015).

Authors of previous studies conducted in the Barrenlands found that several habitat variables influenced the presence of YOY Arctic grayling, including water depth, water velocity, discharge, substrate, slope, detritus, and instream and overhanging vegetation (Jones & Tonn, 2004; Artym, 2016; Baker et al., 2017). Of these variables, discharge, slope, and substrate (expressed as % inorganic) provided some explanation of stream occupancy in our study. We sampled a wider range of stream conditions than previous studies, and it is possible that instream variables (e.g., water depth, water velocity) are less important when predicting occupancy over a larger spatial scale or more diverse landscape. Our measurements of instream habitat variables under sometimes extreme conditions, such as during heavy rain events, likely confounded any relationships with occupancy, and precluded meaningful comparisons of results among studies. We conclude that connectivity, inferred through the variables of contributing upstream lake area and land cover, were the primary driver of YOY occupancy in our study. Connectivity has been identified as an important factor for explaining YOY presence in other studies (Jones & Tonn, 2004; Artym, 2016; Baker et al., 2017), as habitat variables such as discharge, slope, substrate, water depth, and water velocity often reflect, or are related to, stream connectivity.

Detection

Detection efficiency was high overall; however, increases in average water depth and velocity reduced the probability that YOY would be detected. A general trend of decreasing detection efficiency with increasing depth during visual surveys has been observed in previous studies of YOY Arctic grayling (Artym, 2016) and smallmouth bass [*Micropterus dolomieu* (Lacepéde, 1802)] YOY (Brewer & Ellersieck, 2011). While neither study found a statistically significant relationship between velocity and probability of detection, average site velocities were low (0.085 m/s for Artym (2016) and 0.054 m/s for Brewer & Ellersieck (2011)) relative to velocities measured in this study (0.24 m/s).

Overdispersion ($\widehat{c}$ of 3.4) was observed in the model of detection probability. Unmodeled heterogeneity in detection probability was the suspected cause of overdispersion (i.e., there was a factor influencing the detection probability that was not accounted for in the model), and was likely due to variation in abundance of YOY among streams. The size of the local population at each replicate impacts detection probability, and variation in abundance can be the leading cause of heterogeneity in detection probabilities in occupancy studies (Royle & Nichols, 2003). For juvenile bull tout [*Salvelinus confluentus* (Suckley, 1859)] occupying mountain streams in the Northwest Territories, detection probability is high (p = 0.78) in core habitat areas, but is greatly reduced (p = 0.48) in fringe habitats near distributional boundaries (Mochnacz et al., 2021), where abundance is likely lower. Most occupied streams surveyed in this study had perfect detection (62.5%), and are likely core habitat areas for YOY grayling. What constitutes fringe habitat for YOY Arctic graying in Barrenland streams is poorly understood. While collection of additional stream variables, such as food availability (see Jones et al., 2003b), may help to identify fringe habitat and account for the unmodeled heterogeneity in detection, it is also likely that fringe habitat for YOY rearing in streams is correlated with the distributional patterns and habitat requirements of adults. Developing a broader understanding of habitat use of all life stages of Arctic grayling in the Barrenlands may help to identify more cryptic variables that are related to core and fringe stream habitat for YOY.

Conclusion

Critical knowledge gaps regarding ecology and life history of northern populations of Arctic grayling preclude accurate or precise predictions regarding potential impacts of human-induced stressors. This is particularly true for regions where habitat use is poorly understood, such as in Arctic Barrenland landscapes. The Barrenlands are dominated by networks of seasonally connected lakes and streams that allow adfluvial populations of Arctic grayling to migrate, spawn, and rear. Results of our study indicate that suitability of Barrenland stream habitat for YOY Arctic grayling is limited by connectivity. In the Barrenlands, the importance of headwater lakes in ensuring the permanence of stream connections (persistence of flow) is evident, given the strong correlation between contributing upstream surface area and stream discharge. In lowland regions, stream connectivity within chain-lake systems is well defined, and even a small contributing upstream lake area can promote sustained flow through the open water season. For upland regions, a larger contribution from upstream lakes is required to maintain connectivity, and thus there are fewer suitable streams within this landscape for YOY to rear. Through occupancy modeling we identified that surrogates of connectivity (i.e., contributing upstream lake area and landcover), which can be calculated using publicly available data (e.g., Campbell et al., 2012; Natural Resources Canada, 2016), adequately predict YOY Arctic grayling stream use in the Barrenlands. Use of this model as a predictive tool could lessen the considerable financial and logistical constraints of conducting remote Arctic fieldwork and facilitate more focused field programs to inform conservation and mitigation plans.

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Author contributions Conceptualization: HKS; Methodology: JRE, HKS, PAC; Formal analysis and investigation: JRE; Writing—original draft preparation: JRE; Writing—review and editing: HKS, PAC; Funding acquisition: HKS; Supervision: HKS.

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Data availability Data from this study are available from the corresponding author upon request.

Code availability Code from this study are available from the corresponding author upon request.

Declarations

Conflict of interest No conflict of interest.

Ethical approval This study was performed under Nunavut Research Institute Scientific Research Licence 02 023 18 N-M and 03 013 19R-M and under Kivalliq Inuit Association Certificate of Exemption KVX18N04.

Consent for publication Figure 2 was modified, with permission from Campbell et al., 2012.

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APPENDIX C

Shoreline Electrofishing Data

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021. NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17373	10-Aug-21	2021	A20	NSSB	2.6	67.10
17374	10-Aug-21	2021	A20	NSSB	1.4	61.30
17375	10-Aug-21	2021	A20	NSSB	0.9	52.80
17376	10-Aug-21	2021	A20	NSSB	1.1	59.10
17377	10-Aug-21	2021	A20	NSSB	0.4	45.50
17378	10-Aug-21	2021	A20	NSSB	2.0	65.20
17379	10-Aug-21	2021	A20	NSSB	1.2	55.10
17380	10-Aug-21	2021	A20	NSSB	1.0	55.90
17381	10-Aug-21	2021	A20	NSSB	1.1	52.30
17382	10-Aug-21	2021	A20	NSSB	1.0	53.30
17383	10-Aug-21	2021	A20	NSSB	0.5	45.40
17385	10-Aug-21	2021	A20	NSSB	1.2	62.60
17386	10-Aug-21	2021	A20	NSSB	1.0	55.10
17387	10-Aug-21	2021	A20	NSSB	1.0	55.40
17388	10-Aug-21	2021	A20	NSSB	1.4	65.20
17389	10-Aug-21	2021	A20	NSSB	1.2	60.70
17390	10-Aug-21	2021	A20	NSSB	1.3	61.00
17391	10-Aug-21	2021	A20	NSSB	0.9	52.30
17392	10-Aug-21	2021	A20	NSSB	0.9	51.20
17368	10-Aug-21	2021	A20	SLSC	2.0	61.90
17369	10-Aug-21	2021	A20	SLSC	0.7	45.20
17370	10-Aug-21	2021	A20	SLSC	0.6	44.80
17371	10-Aug-21	2021	A20	SLSC	0.3	33.80
17372	10-Aug-21	2021	A20	SLSC	0.2	33.20
17393	10-Aug-21	2021	A20	SLSC	0.9	49.10
17406	12-Aug-21	2021	A65	NSSB	1.2	59.40
17407	12-Aug-21	2021	A65	NSSB	1.2	60.10
17408	12-Aug-21	2021	A65	NSSB	-	-
17394	12-Aug-21	2021	A65	SLSC	3.3	71.00
17395	12-Aug-21	2021	A65	SLSC	0.6	44.90
17396	12-Aug-21	2021	A65	SLSC	1.8	62.80
17397	12-Aug-21	2021	A65	SLSC	3.8	77.30
17398	12-Aug-21	2021	A65	SLSC	3.6	74.00
17399	12-Aug-21	2021	A65	SLSC	4.2	82.10
17400	12-Aug-21	2021	A65	SLSC	0.7	44.90
17401	12-Aug-21	2021	A65	SLSC	0.6	40.00
17402	12-Aug-21	2021	A65	SLSC	1.6	61.00
17403	12-Aug-21	2021	A65	SLSC	0.7	47.10
17404	12-Aug-21	2021	A65	SLSC	1.1	53.10
17405	12-Aug-21	2021	A65	SLSC	0.6	42.10
17409	13-Aug-21	2021	A44	SLSC	0.3	37.00
17410	13-Aug-21	2021	A44	SLSC	1.8	62.90
17411	13-Aug-21	2021	A44	SLSC	1.9	65.10
17412	13-Aug-21	2021	A44	SLSC	1.6	60.10
17413	13-Aug-21	2021	A44	SLSC	0.2	33.00
17443	14-Aug-21	2021	B03	NSSB	1.0	56.10
17444	14-Aug-21	2021	B03	NSSB	0.8	52.80
17436	14-Aug-21	2021	B03	SLSC	2.7	70.90
17437	14-Aug-21	2021	B03	SLSC	0.9	50.50
17438	14-Aug-21	2021	B03	SLSC	1.2	55.70
17439	14-Aug-21	2021	B03	SLSC	0.8	50.50

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021. NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17440	14-Aug-21	2021	B03	SLSC	1.0	50.70
17441	14-Aug-21	2021	B03	SLSC	1.1	54.20
17442	14-Aug-21	2021	B03	SLSC	0.2	34.30
17430	14-Aug-21	2021	WTL	NSSB	0.9	55.10
17431	14-Aug-21	2021	WTL	NSSB	1.2	54.80
17432	14-Aug-21	2021	WTL	NSSB	1.0	57.50
17433	14-Aug-21	2021	WTL	NSSB	0.8	57.20
17434	14-Aug-21	2021	WTL	NSSB	1.0	55.10
17415	14-Aug-21	2021	WTL	SLSC	5.0	81.00
17416	14-Aug-21	2021	WTL	SLSC	6.8	89.90
17417	14-Aug-21	2021	WTL	SLSC	2.3	65.00
17418	14-Aug-21	2021	WTL	SLSC	3.3	81.10
17419	14-Aug-21	2021	WTL	SLSC	1.6	59.50
17420	14-Aug-21	2021	WTL	SLSC	4.6	88.20
17421	14-Aug-21	2021	WTL	SLSC	1.7	62.70
17422	14-Aug-21	2021	WTL	SLSC	2.3	66.10
17423	14-Aug-21	2021	WTL	SLSC	1.8	59.30
17424	14-Aug-21	2021	WTL	SLSC	1.7	60.20
17425	14-Aug-21	2021	WTL	SLSC	1.0	51.60
17426	14-Aug-21	2021	WTL	SLSC	0.4	38.70
17427	14-Aug-21	2021	WTL	SLSC	0.6	40.80
17428	14-Aug-21	2021	WTL	SLSC	0.7	46.80
17429	14-Aug-21	2021	WTL	SLSC	14.2	109.80
17446	15-Aug-21	2021	LK8	SLSC	1.4	59.00
17447	15-Aug-21	2021	LK8	SLSC	3.0	68.90
17448	15-Aug-21	2021	LK8	SLSC	1.0	52.20
17449	15-Aug-21	2021	LK8	SLSC	1.9	63.70
17450	15-Aug-21	2021	LK8	SLSC	4.6	82.00
17451	15-Aug-21	2021	LK8	SLSC	1.9	62.30
17452	15-Aug-21	2021	LK8	SLSC	1.4	58.70
17453	15-Aug-21	2021	LK8	SLSC	4.1	72.20
17454	15-Aug-21	2021	LK8	SLSC	1.9	61.90
17455	15-Aug-21	2021	LK8	SLSC	1.5	57.20
17485	16-Aug-21	2021	A63	NSSB	0.8	53.40
17486	16-Aug-21	2021	A63	NSSB	1.2	57.30
17487	16-Aug-21	2021	A63	NSSB	1.2	58.10
17488	16-Aug-21	2021	A63	NSSB	1.1	60.20
17489	16-Aug-21	2021	A63	NSSB	0.9	54.00
17490	16-Aug-21	2021	A63	NSSB	1.1	57.10
17491	16-Aug-21	2021	A63	NSSB	0.8	50.00
17492	16-Aug-21	2021	A63	NSSB	1.1	57.10
17493	16-Aug-21	2021	A63	NSSB	1.9	70.50
17494	16-Aug-21	2021	A63	NSSB	2.0	72.90
17495	16-Aug-21	2021	A63	NSSB	1.1	57.90
17496	16-Aug-21	2021	A63	NSSB	1.9	73.20
17497	16-Aug-21	2021	A63	NSSB	0.8	51.10
17498	16-Aug-21	2021	A63	NSSB	0.9	55.30
17499	16-Aug-21	2021	A63	NSSB	1.3	58.40
17500	16-Aug-21	2021	A63	NSSB	0.8	51.10
17456	16-Aug-21	2021	A63	SLSC	4.0	81.00
17457	16-Aug-21	2021	A63	SLSC	4.2	81.00

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021.
NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17458	16-Aug-21	2021	A63	SLSC	0.4	39.00
17459	16-Aug-21	2021	A63	SLSC	0.5	40.20
17460	16-Aug-21	2021	A63	SLSC	0.8	47.20
17461	16-Aug-21	2021	A63	SLSC	1.0	49.90
17462	16-Aug-21	2021	A63	SLSC	0.6	40.90
17463	16-Aug-21	2021	A63	SLSC	0.6	44.30
17464	16-Aug-21	2021	A63	SLSC	0.7	47.20
17465	16-Aug-21	2021	A63	SLSC	0.6	40.80
17466	16-Aug-21	2021	A63	SLSC	3.5	75.10
17467	16-Aug-21	2021	A63	SLSC	0.8	49.10
17468	16-Aug-21	2021	A63	SLSC	0.5	43.10
17469	16-Aug-21	2021	A63	SLSC	0.6	45.30
17470	16-Aug-21	2021	A63	SLSC	0.6	44.40
17471	16-Aug-21	2021	A63	SLSC	0.7	43.00
17472	16-Aug-21	2021	A63	SLSC	1.1	52.90
17473	16-Aug-21	2021	A63	SLSC	0.8	48.20
17474	16-Aug-21	2021	A63	SLSC	0.7	45.20
17475	16-Aug-21	2021	A63	SLSC	0.5	41.20
17476	16-Aug-21	2021	A63	SLSC	0.7	45.10
17477	16-Aug-21	2021	A63	SLSC	0.5	43.00
17478	16-Aug-21	2021	A63	SLSC	0.7	43.60
17479	16-Aug-21	2021	A63	SLSC	0.7	44.20
17480	16-Aug-21	2021	A63	SLSC	0.7	46.00
17481	16-Aug-21	2021	A63	SLSC	0.6	44.90
17482	16-Aug-21	2021	A63	SLSC	1.0	51.80
17483	16-Aug-21	2021	A63	SLSC	0.8	47.20
17484	16-Aug-21	2021	A63	SLSC	0.7	48.20
17518	16-Aug-21	2021	WTL	NSSB	1.0	53.00
17519	16-Aug-21	2021	WTL	NSSB	1.3	57.20
17520	16-Aug-21	2021	WTL	NSSB	0.8	53.10
17521	16-Aug-21	2021	WTL	NSSB	1.4	62.40
17522	16-Aug-21	2021	WTL	NSSB	0.7	43.90
17523	16-Aug-21	2021	WTL	NSSB	1.3	60.20
17524	16-Aug-21	2021	WTL	NSSB	1.0	51.80
17525	16-Aug-21	2021	WTL	NSSB	0.9	56.00
17526	16-Aug-21	2021	WTL	NSSB	1.2	57.50
17527	16-Aug-21	2021	WTL	NSSB	2.5	74.50
17501	16-Aug-21	2021	WTL	SLSC	3.3	68.30
17502	16-Aug-21	2021	WTL	SLSC	3.2	73.30
17503	16-Aug-21	2021	WTL	SLSC	2.8	74.50
17504	16-Aug-21	2021	WTL	SLSC	3.9	79.90
17505	16-Aug-21	2021	WTL	SLSC	2.9	63.00
17506	16-Aug-21	2021	WTL	SLSC	3.8	83.00
17507	16-Aug-21	2021	WTL	SLSC	2.7	68.20
17508	16-Aug-21	2021	WTL	SLSC	0.5	39.30
17509	16-Aug-21	2021	WTL	SLSC	2.0	64.10
17510	16-Aug-21	2021	WTL	SLSC	3.0	70.20
17511	16-Aug-21	2021	WTL	SLSC	3.3	69.30
17512	16-Aug-21	2021	WTL	SLSC	2.1	62.50
17513	16-Aug-21	2021	WTL	SLSC	0.9	47.20
17514	16-Aug-21	2021	WTL	SLSC	0.7	45.10

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021.
NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17515	16-Aug-21	2021	WTL	SLSC	1.9	63.90
17516	16-Aug-21	2021	WTL	SLSC	0.6	42.10
17517	16-Aug-21	2021	WTL	SLSC	1.0	49.80
17530	17-Aug-21	2021	MMT	NSSB	0.5	45.10
17531	17-Aug-21	2021	MMT	NSSB	1.4	64.00
17532	17-Aug-21	2021	MMT	NSSB	1.2	59.80
17533	17-Aug-21	2021	MMT	NSSB	0.8	54.90
17534	17-Aug-21	2021	MMT	NSSB	0.9	54.20
17535	17-Aug-21	2021	MMT	NSSB	0.8	51.60
17536	17-Aug-21	2021	MMT	NSSB	1.6	65.30
17537	17-Aug-21	2021	MMT	NSSB	0.9	52.80
17538	17-Aug-21	2021	MMT	NSSB	0.8	52.10
17539	17-Aug-21	2021	MMT	NSSB	1.0	56.30
17540	17-Aug-21	2021	MMT	NSSB	0.8	52.10
17541	17-Aug-21	2021	MMT	NSSB	0.6	45.20
17542	17-Aug-21	2021	MMT	NSSB	1.3	61.90
17543	17-Aug-21	2021	MMT	NSSB	1.2	58.10
17544	17-Aug-21	2021	MMT	NSSB	0.9	54.00
17545	17-Aug-21	2021	MMT	NSSB	0.6	48.10
17546	17-Aug-21	2021	MMT	NSSB	1.0	54.30
17547	17-Aug-21	2021	MMT	NSSB	1.1	57.20
17548	17-Aug-21	2021	MMT	NSSB	0.9	53.10
17549	17-Aug-21	2021	MMT	NSSB	1.1	58.00
17550	17-Aug-21	2021	MMT	NSSB	0.9	52.90
17551	17-Aug-21	2021	MMT	NSSB	1.5	63.00
17552	17-Aug-21	2021	MMT	NSSB	0.7	51.90
17553	17-Aug-21	2021	MMT	NSSB	1.0	57.10
17554	17-Aug-21	2021	MMT	NSSB	2.2	74.50
17555	17-Aug-21	2021	MMT	NSSB	1.5	61.30
17556	17-Aug-21	2021	MMT	NSSB	1.0	55.20
17557	17-Aug-21	2021	MMT	NSSB	0.8	50.90
17558	17-Aug-21	2021	MMT	NSSB	2.0	69.60
17559	17-Aug-21	2021	MMT	NSSB	0.7	46.20
17560	17-Aug-21	2021	MMT	NSSB	0.9	54.40
17561	17-Aug-21	2021	MMT	NSSB	1.0	54.00
17562	17-Aug-21	2021	MMT	SLSC	1.0	53.30
17563	17-Aug-21	2021	MMT	SLSC	0.8	49.00
17564	17-Aug-21	2021	MMT	SLSC	1.8	65.20
17565	17-Aug-21	2021	MMT	SLSC	0.8	50.10
17566	17-Aug-21	2021	MMT	SLSC	0.3	34.20
17567	17-Aug-21	2021	MMT	SLSC	1.1	52.50
17568	17-Aug-21	2021	MMT	SLSC	0.5	42.00
17569	17-Aug-21	2021	MMT	SLSC	2.0	65.20
17570	17-Aug-21	2021	MMT	SLSC	1.5	58.90
17571	17-Aug-21	2021	MMT	SLSC	1.6	60.90
17572	17-Aug-21	2021	MMT	SLSC	1.4	57.00
17573	17-Aug-21	2021	MMT	SLSC	2.2	65.00
17574	17-Aug-21	2021	MMT	SLSC	2.0	64.30
17575	17-Aug-21	2021	MMT	SLSC	0.4	38.20
17576	17-Aug-21	2021	MMT	SLSC	0.9	50.20
17577	17-Aug-21	2021	MMT	SLSC	2.1	61.90

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021.
NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17578	17-Aug-21	2021	MMT	SLSC	0.4	36.00
17579	17-Aug-21	2021	MMT	SLSC	0.5	39.30
17580	17-Aug-21	2021	MMT	SLSC	2.9	74.30
17581	17-Aug-21	2021	MMT	SLSC	0.5	40.10
17582	17-Aug-21	2021	MMT	SLSC	1.1	52.30
17583	17-Aug-21	2021	MMT	SLSC	0.4	39.00
17584	17-Aug-21	2021	MMT	SLSC	2.1	63.10
17585	17-Aug-21	2021	MMT	SLSC	1.6	60.00
17586	17-Aug-21	2021	MMT	SLSC	1.9	60.90
17587	17-Aug-21	2021	MMT	SLSC	1.5	58.10
17588	17-Aug-21	2021	MMT	SLSC	0.5	39.00
17589	17-Aug-21	2021	MMT	SLSC	0.5	39.90
17590	17-Aug-21	2021	MMT	SLSC	0.4	36.20
17591	17-Aug-21	2021	MMT	SLSC	0.4	40.00
17592	17-Aug-21	2021	MMT	SLSC	0.4	37.20
17626	18-Aug-21	2021	A44	NSSB	2.0	68.80
17627	18-Aug-21	2021	A44	NSSB	1.3	63.30
17628	18-Aug-21	2021	A44	NSSB	1.1	57.90
17629	18-Aug-21	2021	A44	NSSB	0.7	51.10
17623	18-Aug-21	2021	A44	SLSC	0.9	49.20
17624	18-Aug-21	2021	A44	SLSC	0.9	50.10
17625	18-Aug-21	2021	A44	SLSC	1.5	58.10
17616	18-Aug-21	2021	B03	NSSB	1.2	56.10
17617	18-Aug-21	2021	B03	NSSB	0.9	52.90
17618	18-Aug-21	2021	B03	NSSB	1.3	58.30
17619	18-Aug-21	2021	B03	NSSB	0.9	53.40
17620	18-Aug-21	2021	B03	NSSB	1.2	57.30
17621	18-Aug-21	2021	B03	NSSB	1.0	55.80
17622	18-Aug-21	2021	B03	NSSB	1.2	57.10
17593	18-Aug-21	2021	B03	SLSC	1.5	56.30
17594	18-Aug-21	2021	B03	SLSC	1.7	60.10
17595	18-Aug-21	2021	B03	SLSC	0.5	39.00
17596	18-Aug-21	2021	B03	SLSC	4.8	84.20
17597	18-Aug-21	2021	B03	SLSC	0.6	44.00
17598	18-Aug-21	2021	B03	SLSC	0.5	41.10
17599	18-Aug-21	2021	B03	SLSC	0.4	38.50
17600	18-Aug-21	2021	B03	SLSC	0.5	41.90
17601	18-Aug-21	2021	B03	SLSC	2.3	63.10
17602	18-Aug-21	2021	B03	SLSC	0.4	39.50
17603	18-Aug-21	2021	B03	SLSC	2.9	69.00
17604	18-Aug-21	2021	B03	SLSC	2.6	72.10
17605	18-Aug-21	2021	B03	SLSC	1.7	61.10
17606	18-Aug-21	2021	B03	SLSC	0.6	43.50
17607	18-Aug-21	2021	B03	SLSC	0.4	40.00
17608	18-Aug-21	2021	B03	SLSC	0.9	49.30
17609	18-Aug-21	2021	B03	SLSC	0.6	44.50
17610	18-Aug-21	2021	B03	SLSC	0.5	43.10
17611	18-Aug-21	2021	B03	SLSC	1.1	51.00
17612	18-Aug-21	2021	B03	SLSC	1.6	58.10
17613	18-Aug-21	2021	B03	SLSC	1.0	52.50
17614	18-Aug-21	2021	B03	SLSC	0.9	50.50

Table C-1: Small-bodied fish collected through shoreline electrofishing in FHOMP study lakes in 2021. NNSB = Ninespine Stickleback; SLSC = Slimy Sculpin

Fish ID	Date	Year	Site	Species	Weight (g)	Total Length (mm)
17615	18-Aug-21	2021	B03	SLSC	2.1	63.20