Habitat use of young-of-year Arctic Grayling (*Thymallus arcticus*) in Barrenland streams of central Nunavut, Canada

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Arctic Grayling, a species within the family Salmonidae that is valued by sport fishers and Indigenous communities, is distributed throughout a diversity of northern landscapes. While Arctic Grayling are known to be sensitive to perturbations in habitat and water quality, our understanding of constraints on their distribution is incomplete, particularly in the vast subarctic Barrenlands region. Understanding the habitat requirements and distribution of Barrenland populations of Arctic Grayling is necessary to develop effective conservation policies, avoid or mitigate potential impacts of mining and other development, and evaluate population distribution trends over time. Barrenland populations of Arctic Grayling rely on seasonally connected networks of lakes and streams to migrate, spawn, and rear. Knowledge of stream conditions and characteristics that are suitable for rearing young-of-year Arctic Grayling is critical for understanding and predicting variability in recruitment, and thus to ensuring the continued persistence of Barrenland populations. In summer 2019, visual surveys assessing the presence/absence of young-of-year Arctic Grayling were conducted at 49 streams in the Barrenlands region near Baker Lake, Nunavut. Occupancy modeling was used to relate a comprehensive suite of stream habitat (e.g., depth, velocity, water temperature) and landscape (e.g., land cover, contributing upstream lake area) variables to the presence/absence of young-of-year Arctic Grayling. Quantification of detection efficiency, and variables that affect detection efficiency, allowed for improved inferences on species-habitat relationships. While detection efficiency was negatively influenced by water depth and water velocity, the best predictors of young-of-year grayling occupancy were the total area of contributing upstream lakes and the landcover (upland/lowland) of the stream basin. These results suggest that the position of streams within Barrenland landscapes is related to reliability of stream connectivity, and thus suitability for young-of-year. Both explanatory variables are important in promoting hydrologic connectivity throughout the summer rearing period and facilitating the migration of young-of-year to overwintering lakes prior to freeze up. Contributing upstream lake area and land classification data may be obtained remotely, which allows for preliminary predictions of stream suitability to be conducted with minimal financial and logistic effort, and more spatially focused field operations. The occupancy model developed here can be used as a valuable predictive tool for Arctic Grayling young-of-year stream use in the Barrenlands, and will facilitate regulators, scientists,

resource managers, and industry in developing more effective conservation and mitigation plans for fish and fish habitat in areas of resource development.

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AIC	Aikake Information Criteria
AICc	Aikake Information Criteria corrected for small sample sizes
CV	Coefficient of Variation
masl	Meters above sea level
NWT	Northwest Territories
p	Probability of detection
QAICc	Quasi-Aikake Information Criteria corrected for small sample sizes
YOY	Young-of-year
$\hat{c}$	Overdispersion parameter
Ψ	Probability of occupancy
χ^2	Chi-squared statistic
95% CI	95% Confidence Interval
-2*l*	-2loglikelihood, or deviance

1. 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 impacts, and direct restoration efforts (Jones et al. 2017). Arctic Grayling (*Thymallus arcticus*) is often a focal species in northern research and environmental impact statements, as they are valued by many stakeholders, including sport fishers (Scott and Crossman 1973; Read and Roberge 1984) and Indigenous communities (e.g., Kitikmeot Inuit Association 2006). In Arctic Barrenland landscapes, they often adopt a migratory life history (e.g., Jones et al. 2003; Baker et al. 2017), which makes them susceptible to habitat fragmentation and alterations in hydrologic flow and connectivity (Carl et al. 1992; Northcote 1995). Arctic Grayling also have low tolerance to increases in turbidity (Birtwell et al. 1984) and changes in water temperature (Haugen and 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). While Arctic Grayling are highly valued by many stakeholders, there is a distinct paucity of data for populations in northern ecoregions. The resulting 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, and this is particularly true for regions where habitat use is poorly understood, such as in Arctic Barrenland landscapes.

1.1 Arctic Grayling life history

Arctic Grayling is a northern freshwater fish species that occurs in mainland drainages of Nunavut, Northwest Territories, Yukon, and Alaska, as well as northern portions of Manitoba, Saskatchewan, Alberta, and British Columbia (Scott and Crossman 1973; Stewart et al. 2007). Arctic Grayling is an iteroparous (multiple reproductive cycles over a lifetime) member of the Salmonidae family, and is best identified by its prominent, showy dorsal fin. Similar to other salmonids, Arctic Grayling exhibit plasticity in life history traits, which allows populations to persist in a variety of aquatic environments throughout their range (Scott and Crossman 1973; Evans et al. 2002; Sawatzky et al. 2007). Previous researchers have identified several life history strategies, and described lacustrine, fluvial, and adfluvial life history types that vary in terms of habitats used for overwintering, foraging, and spawning (Scott and Crossman 1973; Bruyn and McCart 1974; Northcote 1995; Stewart et al.

2007). Lacustrine populations of Arctic Grayling are relatively uncommon and complete all life history stages, including spawning, within lakes (Northcote 1995). Fluvial populations of Arctic Grayling complete all life history stages within lotic habitats, and migrate from larger rivers and streams to smaller tributaries during the open water season to forage and/or spawn (Scott and Crossman 1973; West et al. 1992). Adfluvial populations of Arctic Grayling use both lentic and lotic habitats. Individuals of all age classes within adfluvial populations overwinter in lakes. Non-spawning individuals may remain in lakes year-round or migrate to streams to forage during the open water season (Stewart et al. 2007) whereas spawning adults migrate to streams to spawn in early spring, where they may remain until mid-summer or autumn (Reed 1964; Tripp and McCart 1974). Post-spawning adults commonly return to larger lakes for summer feeding shortly after spawning (Deegan and Peterson 1992; Stewart et al. 2007).

For both fluvial and adfluvial populations of Arctic Grayling, spawning migrations begin during spring freshet, either before ice break up (Reed 1964) or shortly thereafter (Craig and Poulin 1975; Jones et al. 2003; Heim et al. 2015). Spawning occurs over a variety of substrates that range from silt to cobble and boulder (Scott and Crossman 1973; Northcote 1995; Stewart et al. 2007); however, most spawning occurs over small, unembedded gravel (Stewart et al. 2007). Spawning commences when stream temperatures reach 4-6°C (Reed 1964; Tripp and McCart 1974; Jones et al. 2003; Stewart et al. 2007).

Egg incubation time varies with temperature (Stewart et al. 2007) and takes 8-32 days at 15.5-5.8°C, respectively (Evans et al. 2002). Young-of-year (YOY) remain in their natal streams late into the summer, and out-migrate just before freeze-up (Heim et al. 2015). Various environmental factors have been suggested to trigger migration, including decreasing day length (Buzby and Deegan 2004), increasing water flow (Buzby and Deegan 2004), and decreasing water temperature (Heim et al. 2015), although other studies have found no evidence for environmental conditions serving as a cue for migration (Craig and Poulin 1975). Timing of YOY migration has also been shown to be related to fish size and body condition, with larger YOY and those with higher condition migrating earlier to overwintering habitats (Heim et al. 2016).

1.2 Barrenland populations of Arctic Grayling

Life history and habitat use of Barrenland populations of Arctic Grayling are influenced by the geomorphology and climate of the region. The Barrenlands are characterized by low elevation gradients, continuous permafrost, and abundant shallow lakes that are not well integrated into large drainage systems (Baki et al. 2012). Streams in this region are short, often only a few hundred meters to a few kilometers in length, and provide important connections between lakes (Jones et al. 2003). Barrenland populations of Arctic Grayling commonly exhibit an adfluvial life history, and therefore rely on connected networks of lakes and streams to migrate, spawn, and rear (Jones and Tonn 2004; Baker et al. 2017).

The hydrology of the Barrenlands is governed by a highly seasonal climate. Winters can be more than nine months long, during which time lakes and large rivers are ice-covered and streams are frozen to the bottom (Jones et al. 2003). Arctic Grayling must migrate from streams prior to freeze-up, while there is still adequate flow, to access suitable overwintering habitat in connected lakes. During spring freshet, the rapidly melting snowpack recharges lake basins and re-connects lake-stream-river complexes. In summer, evaporation typically exceeds precipitation (Jones et al. 2009; Baki et al. 2012), resulting in a slow decrease in lake water levels and a corresponding reduction in stream discharge. Often, by late summer, lake levels are reduced to near or below the elevation of outflow, resulting in low stream flows and sometimes discontinuous/dry stream channels (Woo and Mielko 2007; Baki et al. 2012). Thus, stream conditions and connectivity vary seasonally, which limits availability of suitable rearing habitat for YOY in their natal streams. Understanding stream conditions and characteristics that are suitable for rearing YOY is critical for understanding and predicting recruitment, and thus to ensuring the continued persistence of Barrenland populations of Arctic Grayling.

Barrenland streams have diverse physical characteristics (Jones et al. 2003), yet data on stream habitat preferences of Arctic Graying in this region are limited. To date, two studies have assessed and quantified habitat use of YOY Arctic Grayling in Barrenland streams. Jones and Tonn (2004) studied microhabitat preferences of YOY in a Barrenland stream in the Northwest Territories (NWT) by sampling habitat use of individual YOY and modeling results as resource selection functions. In another area of the Northwest Territories, Artym (2016) and Baker et al. (2017) developed occupancy models based on YOY presence/absence surveys and habitat data in a total of nineteen Barrenland streams. Authors of both studies found numerous habitat variables influenced presence of Arctic Grayling YOY, including water depth, water velocity, discharge, substrate, slope, detritus, and instream and overhanging vegetation. Habitat variables that indicate the probability of YOY use/occupancy are presented in Figure 1, and were developed from resource selection curves from Jones and Tonn (2004) and occupancy probability functions from Baker et al. (2017). Additional habitat variables influencing YOY habitat use identified by (Artym 2016) are provided in Table 1. Some results are consistent among studies; water velocity and water depth preferences for the 38-57 mm YOY in Jones and Tonn (2004) show a similar range and trend to those found by Baker et al. (2017). Further, both Jones and Tonn (2004) and Artym (2016) identify overhanging vegetation as an important habitat variable for Arctic Grayling YOY. Jones and Tonn (2004) identified a contrast in habitat use between small YOY (15-21 mm) observed in mid-July and large YOY (38-57 mm) observed mid-August; these results indicate that microhabitat use changes as YOY increase in size. Following emergence, YOY congregate in shallow, low-flow areas, but become increasingly solitary and move into deeper and higher-velocity water as they grow (Jones and Tonn 2004).

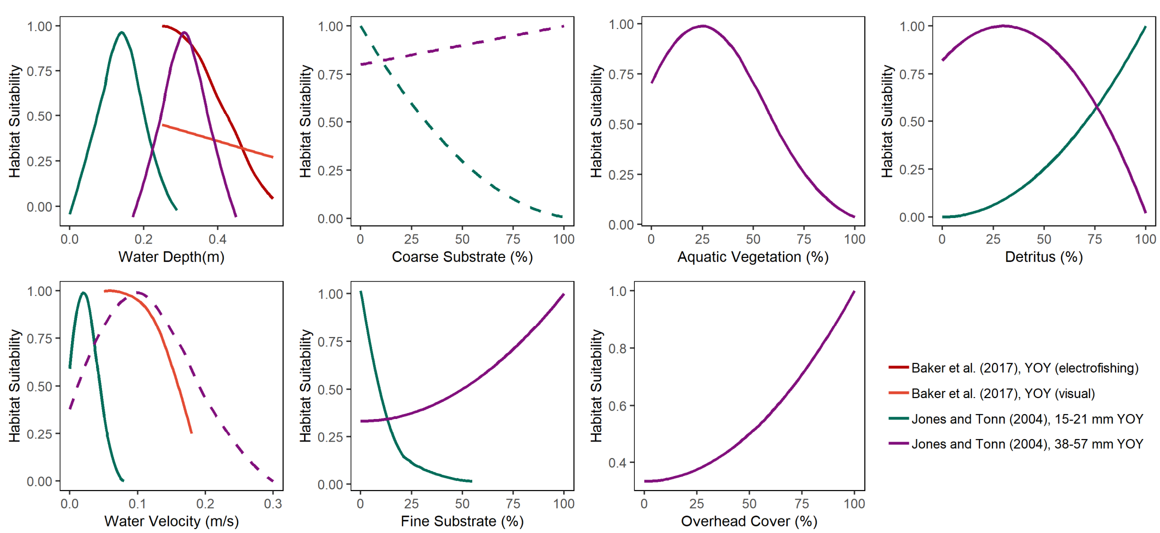


Figure 1. Observed habitat variables in Barrenland streams occupied by Arctic Grayling YOY, reproduced and synthesized from Jones and Tonn (2004) and Baker et al. (2017). Solid lines represent variables that contributed significantly to the models, whereas dashed lines represent variables that did not contribute significantly. Fine substrate includes clay, sand, and silt; coarse substrate includes cobble and boulder.

Table 1. Habitat variables found by Artym (2016) to affect Arctic Grayling YOY occupancy in Barrenland streams.

Habitat Variable	**Observed Range**	**Arctic Grayling YOY Trend**
Stream discharge	0-0.3 m^3/s	Decreasing presence with increasing discharge
Slope	0-4°	Increasing presence with increasing slope
Distance to overwintering habitat	0-1,500 m	Decreasing presence with increasing distance
Overhanging vegetation	Good (>50%) Poor (<50%)	Higher presence with good overhanging vegetation

While the studies conducted by Jones and Tonn (2004), Artym (2016), and Baker et al. (2017) provide useful data on the habitat needs of YOY Arctic Grayling in Barrenland landscapes, the spatial range investigated is small (a total of 20 streams across four drainage basins in NWT), and the full range of stream habitat conditions present in the Barrenlands thus remains under-sampled, potentially limiting our understanding of Arctic Grayling YOY habitat use across the landscape. Additionally, studies to date have primarily focused on stream-level variables thought to influence habitat suitability (see Stewart et al. 2007; Danhoff et al. 2017); few have quantified the influence of regional variables on habitat use within streams. Regional factors such as climate, geology, and hydrology are known to influence fish species composition and abundance (Hershey et al. 2006; Laske et al. 2016), and effects of these factors on Arctic Grayling habitat use deserve further study.

1.3 Influence of landscape on Arctic Grayling habitat suitability

The influence of geomorphic features on dispersal and habitat use of Arctic Grayling remains poorly quantified and generally focuses on lake occupancy. Hershey et al. (1999) developed a conceptual model to predict the distribution of fishes in Alaskan Arctic lakes based on observations of geomorphic variables, which included lake depth, lake surface area, and lake outflow gradient. Hershey et al. (1999) suggested that Arctic Graying are widely distributed and that two variables influence their presence/absence in lakes: insufficient depth, which limits species distribution universally, and very high outflow gradients, which acts as a barrier to colonization. Expanding on this, Hershey et al. (2006) sampled 168 Alaskan Arctic lakes and used a classification and regression tree analysis to predict species presence and absence. The classification results for Arctic Grayling suggested that lake order (a measure of the degree of surface water connections to the stream network, as defined by Riera et al. (2000)), outflow gradient, and lake depth explained distribution. However, of five species for which classification and regression trees were created, the Arctic Grayling tree was the least successful, correctly predicting presence and absence only 68% and 66% of the time, respectively.

Landscape-level variables may be of greater importance in predicting presence or absence of Arctic Grayling YOY in Barrenland streams compared to lakes. Barrenland streams are largely colluvial, meaning fluvial processes are relatively ineffective at moving material and influencing channel morphology (Jones and Tonn 2004). This results in generally stable, poorly sorted streams, where attributes such as substrate and geomorphology are a product of the immediate surrounding landscape. The landscape can be surprisingly variable, with bedrock forming broad sloping uplands and lowlands. Outcrops covered with till are dominant, and prominent esker ridges are common across the landscape (Campbell et al. 2012). Soil characteristics and moisture regimes range from hydric graminoid peat, to mesic shrub tundra and xeric boulder lichen tundra (Campbell et al. 2012). Soil and moisture conditions not only drive vegetation communities, but also affect stream conditions. A landscape that is wet and poorly-drained can promote hydrologic connectivity, and allow stream flows to persist through summer whereas well-drained boulder fields derived from glacial till can result in isolation of streams or subsurface stream flow. This is most prevalent later in the summer, when water levels are lower (Jones et al. 2003; Courtice et al. 2014).

Over 20% of the Barrenlands are covered by water (Jones et al. 2003; Campbell et al. 2012), and the landscape is dominated by networks of connected lakes and streams. The importance of considering how stream-lake connectivity influences abundance and distribution of fish species across complex drainage networks, such as those in the Barrenlands, is becoming increasingly evident (e.g., Jones 2010; Haynes et al. 2014; Laske et al. 2016; Pépino et al. 2017; Heim et al. 2019). Water stored in lakes can stabilize the flow regime of outlet streams (Dorava and Milner 2000; Jones 2010), with larger upstream lakes providing a source of water throughout the summer (Jones et al. 2003); streams draining larger lakes are thus more likely to have sustained flow during arid conditions (Jones 2010). Nearly all streams in the Barrenlands originate as lake outlets (Jones et al. 2003), yet the size and number of headwater lakes that contribute to a stream varies greatly. Therefore, the position of the stream within the chain lake system 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.

1.4 Methods for assessing fish distribution and habitat use

Understanding spatial variation in the density or occupancy of a species across a landscape allows for inferences of habitat suitability (MacKenzie 2018), and requires accurate information on the presence or absence of the species within the range of available habitats of interest. Methods for assessing suitable habitat for fish species or specific life stages of fish species that occupy lotic environments, such as Arctic Grayling YOY, have advanced as computing power and statistical methods improved. Early practitioners/researchers used habitat suitability indices, which were developed using a combination of literature and expert opinion, and yielded graphs of various stream habitat variables (e.g., depth, velocity, temperature) and their associated suitability for the species/life stage (Hubert et al. 1985). The search for more robust methods led to the later development of resource selection functions, which use statistical models to associate presence-only data or presence/absence data with habitat variables (Boyce 2006). This method assumes that sites where a species is identified as absent are correctly classified, and that the detectability of the species is effectively 100% (MacKenzie 2006). However, while detection methods vary by species, they are generally imperfect and can lead to false absences. False absences can result in biased estimates of species' ranges, and misleading inferences about relationships between occupancy and habitat (MacKenzie et al. 2018). Imperfect detection can be exacerbated by many factors, such as weather, habitat type, survey timing, and survey technician. Explicitly accounting for and quantifying false absences, which can be achieved by estimating the probability that a species is present but undetected, provides a more accurate measure of species occupancy (MacKenzie et al. 2018).

A framework for estimating site occupancy rates when detection probabilities are less than perfect (i.e., <100%) was first introduced by MacKenzie et al. (2002). The methodology requires either spatial replication (sampling of replicates within a sample site) or temporal replication (repeated sampling of the same sample site). The sample site is defined as the basic landscape unit over which the presence/absence of the species is being established. A schematic of a spatially replicated occupancy study design is conceptually illustrated in Figure 2.

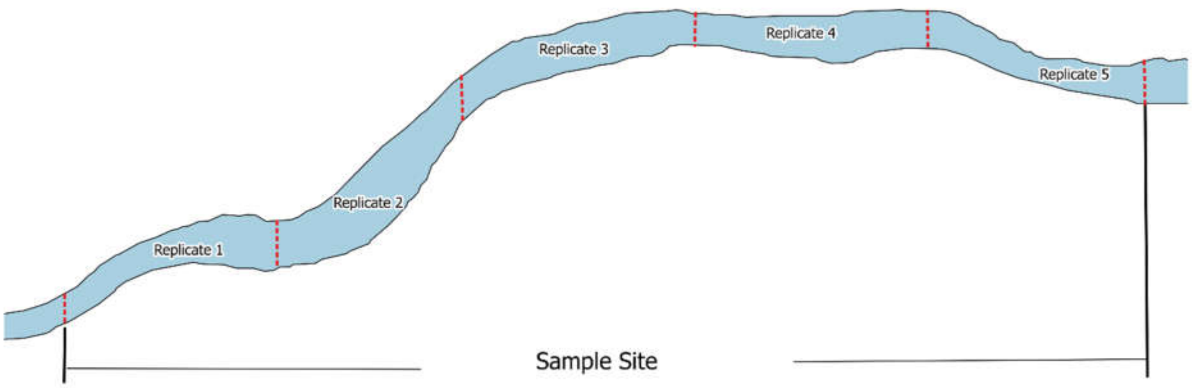


Figure 2. Schematic of spatial replicates within a sample site.

For each spatial replicate, presence or absence of the target species is assessed and covariate data (e.g., habitat, sampling conditions) are collected. After sampling all spatial replicates, the detection history of a sample site can be represented by a series of 0s and 1s, respectively indicating non-detections or detections of the species. If the detection history of a site is 0 across all replicates (i.e., the species was never detected at the site), there are two possible outcomes: the species is absent from the sample site, or the species is present but undetected. Should any survey of a given sample site detect a species, it is assumed the species was present in all spatial replicates, and that non-detections are a result of false absences (sites and replicates have to be carefully chosen to meet this assumption, based on data such as home ranges). The probability of detection can then be estimated. A binomial probability statement can be created for each sample site based on the detection history of the replicates. For example, the probability statement for a sample site with three replicates and a detection history of 0,1,0 would be represented by:

$$P_r(h_j = 010|\psi, p_j) = \psi(1-p_1)p_2(1-p_3)$$

where,

ψ = the probability the site is occupied;

p_j = the probability the species is detected at the replicate in survey j (given presence); and,

h_j = the detection history.

After creating a probability statement for each sample site, the model likelihood is constructed by combining probability statements across all sample sites, and maximum likelihood estimates are obtained. In its most basic form, the model makes several critical assumptions (MacKenzie et al. 2018):

1. Occupancy state (i.e., presence/absence) of the unit does not change during the survey period;
2. Probability of occupancy is equal across all sites;
3. For sites where the species is present, the probability of detecting the species at a replicate is equal across all replicates;
4. Detection of the species at each replicate is independent of detections at other replicates;
5. Detection histories observed at each site are independent; and,
6. Misidentification of species resulting in false positives does not occur.

Extensions to the basic occupancy model have been developed to allow for the violation of these assumptions. For example, autocorrelation in detection histories among replicates can be accounted for. By introducing covariates, assumptions of equal occupancy probability across all replicates and equal detection probability across all sites can also be relaxed. Examples of covariates that may account for variation among replicates (i.e., affecting detection probability), include time, date, and survey technician, while covariates that may account for variation among sites (i.e., affecting occupancy probability) are typically habitat-related (e.g., water temperature, substrate, and discharge). An array of candidate models can be constructed, incorporating both detection and occupancy covariates. Results allow for inferences about which habitat variables best explain occupancy of the target species within the study area (MacKenzie et al. 2018).

1.5 Study rationale

Like other migratory fish species, adfluvial populations of Barrenland Arctic Grayling are susceptible to habitat fragmentation and alterations in hydrologic flow and connectivity (Carl et al. 1992; Northcote 1995), which are common impacts of industrial development and predicted impacts of climate change in northern and Arctic regions (Reist et al. 2006). The Barrenlands region is experiencing an increase in mineral resource development; in Nunavut, mineral production increased 2.7 fold from 2010 to 2017 (Natural Resources Canada 2018a), and previous resource developments have had negative effects on Arctic Grayling populations (e.g., (Jones and Tonn 2004; Baker et al. 2017). Incomplete understanding of habitat use by adfluvial Arctic Grayling in Barrenland regions currently limits the ability of regulators, scientists, and industry to develop effective conservation and mitigation plans in advance of development, and predict potential cumulative effects of resource development and climate change.

1.6 Local context

Located within the Barrenlands, the Hamlet of Baker Lake (Qamani'tuaq) is the fourth largest and only inland community in Nunavut (population of 2,069, (Statistics Canada 2016)). Located within the Wager Bay Plateau ecoregion at the southernmost extent of the Northern Arctic Ecozone (Campbell et al. 2012), it 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).

The region is currently experiencing increased development due to two nearby gold deposits. The Meadowbank gold mine is located approximately 80 km north of Baker Lake (Figure 3), and an all-weather access road connecting the Hamlet to the mine site was completed in the spring of 2008 (Agnico Eagle Mines Limited 2010). The road, which is approximately 110 km long, weaves through the Barrenland tundra, navigating around numerous lakes and crossing approximately 25 stream channels. While many of the channels crossed by the road are ephemeral and poorly defined, at least six streams support Arctic Grayling during migration, spawning, and/or rearing stages of their life cycle (Cumberland Resources Ltd. 2005; Azimuth Consulting Group 2008). The streams where Arctic Grayling have not been found were classified as unsuitable due to insufficient flow or inappropriate spawning substrate (Cumberland Resources Ltd. 2005), but the factors that determine suitability of stream habitat for Arctic Grayling in the region remain largely unknown.

Approximately 50 km northwest of Meadowbank is Amaruq, a gold deposit that recently completed its development phase and entered operation. Prior to the extension of the all-weather access road from Meadowbank to Amaruq, Arctic Grayling were detected in one of eleven stream channels surveyed (C. Portt and Associates 2015). The reduced presence of Arctic Grayling in these channels relative to those between Baker Lake and Meadowbank is likely related to habitat suitability, but knowledge of habitat requirements is lacking. It is anticipated that future industrial development will continue in the region. Understanding the factors that determine the presence or absence of Arctic Grayling across the landscape will facilitate informed dialogue among industry, regulators, and the public, and aid in the development of sound conservation, mitigation, and compensation plans for this highly valued species.

1.7 Study Objective

The objective of this study is to identify habitat variables that best explain the distribution (presence/absence) of Arctic Grayling young-of-year in Barrenland streams near Baker Lake, in central Nunavut.

It was hypothesized that the distribution of Arctic Grayling young-of-year in Barrenland streams would be explained by habitat variables associated with cover (e.g., substrate type, overhanging vegetation) and foraging conditions that maximize food availability while minimizing energy expenditure (e.g., stream velocity, water temperature).

2. Methods

2.1 Study Area and Land Classification

The study area is situated in the Barrenlands, and extends north from the Hamlet of Baker Lake along the 175 km all-weather access road to Amaruq, the northernmost mine in the Meadowbank Complex (Figure 3). Study streams are located within three watersheds: two watersheds are within the Hudson Bay drainage basin, and one is within the Arctic Ocean drainage basin. The extent of the study area was limited to streams 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.

The study area is within a region where ecological land classification data exist. Detailed land classification data for the Arctic is in general sparse, and these data provide an opportunity to explore how land cover types influence stream conditions and ultimately affect habitat suitability for YOY Arctic Grayling. Twelve different land classes are defined within the study area based on moisture and substrate, and range from moist, organic, graminoid tundra to dry, lichen-rock complexes (Figure 4a). While specific composition of vegetation communities adjacent to streams is not anticipated to influence habitat suitability for fish, the general moisture and substrate of the surrounding landscape is expected to have an impact. Therefore, the 12 vegetation communities were reduced to two land classes: 1) upland; and, 2) lowland (Figure 4b). The lowland land class includes poorly drained substrate dominated by organics, whereas the upland land class includes well-drained inorganic substrates, such as gravel, boulder, and bedrock. Representative photos of lowland and upland dominated Barrenland streams are presented in Figure A-1 in Appendix A.

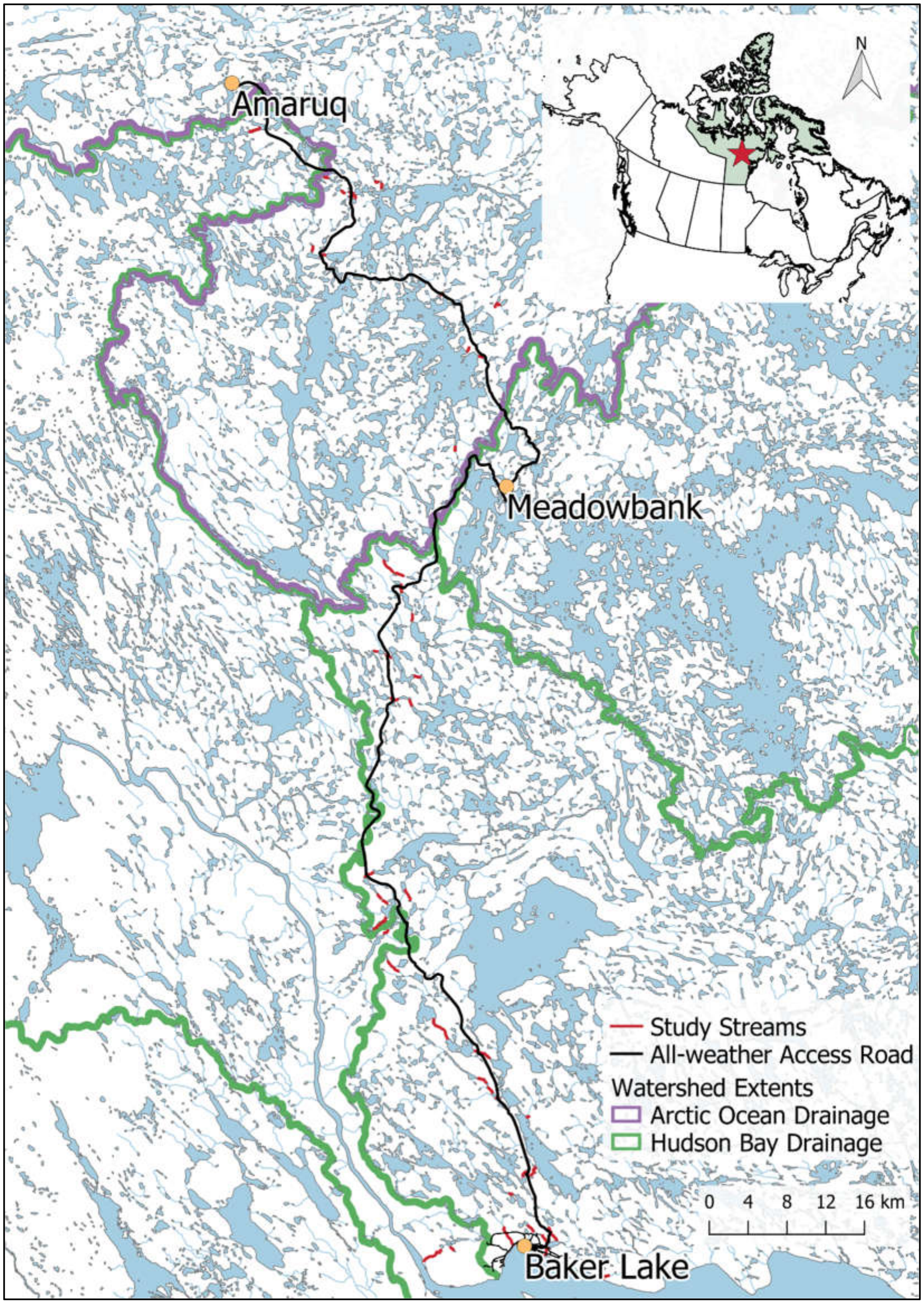
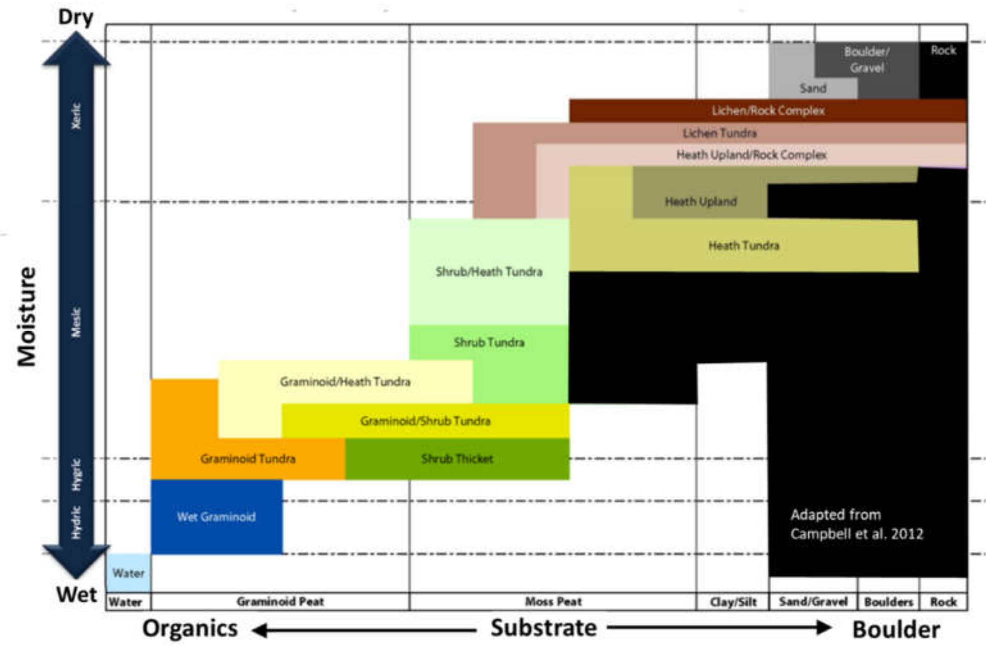


Figure 3. Map of the study area, with watersheds delineated. Study streams, shown in red, were selected randomly from 109 candidate streams that were accessible (within 5 km) from roadways.

(a)



(b)

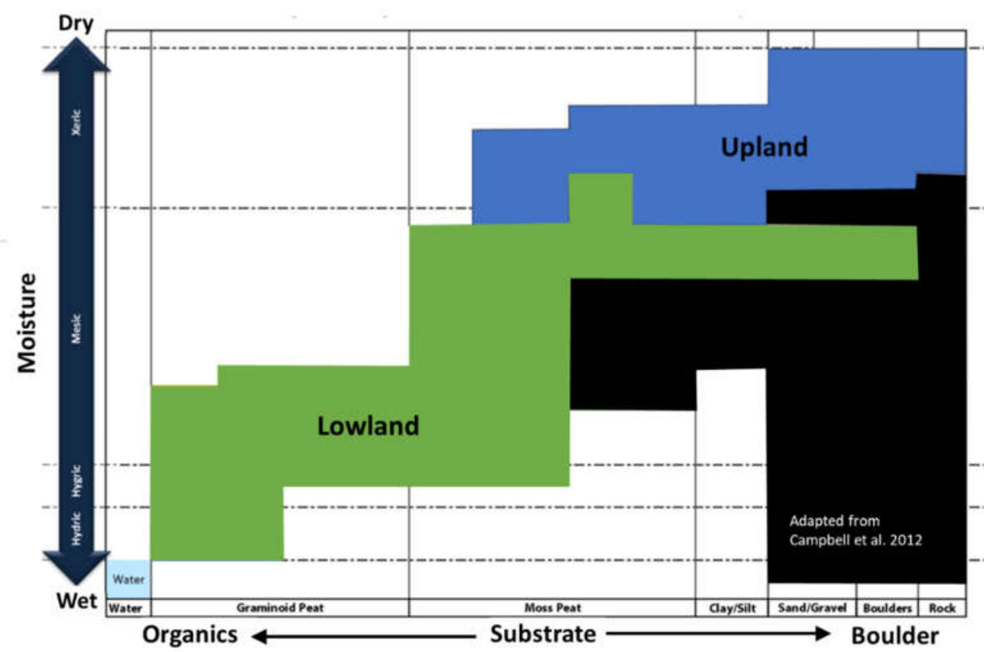


Figure 4. Relationship between moisture and substrate for (a) twelve ecological land cover classes identified in Campbell et al. (2012) and (b) simplified lowland and upland land cover classes to assess relationship with habitat suitability. Delineation of lowland and upland classes was based on moisture. 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 from Campbell et al. (2012).

2.2 Sampling design

2.2.1 General study design

A spatially replicated, single-season occupancy study was designed to assess the probability that a stream within the study region was occupied by YOY Arctic Grayling during the 2019 rearing period. Sample sites were defined as five sequential 30 m surveys (spatial replicates) within a stream, resulting in a total assessed length of 150 m per site. For each spatial replicate, presence or absence of the target species was assessed and covariate data (e.g., habitat, sampling conditions) werecollected. One-hundred and nine candidate streams within the study area were identified using a combination of watershed shapefiles and satellite imagery (either publicly available (Google Earth 2019a, 2019b, 2019c) or supplied by Agnico Eagle). Forty-nine study streams were randomly selected from the candidate list, and a sample site location was randomly chosen within each stream. The number of study streams (n=49) selected was based on the expected range of occupancy probabilities, whereas number of replicates surveyed per stream (n=5) was based on the expected ranges of detection probability; these were estimated using results from previous studies on Arctic Grayling in Barrenland streams (Artym 2016). The aim was to optimize sampling effort while minimizing standard error of occupancy estimates (Figure 5).

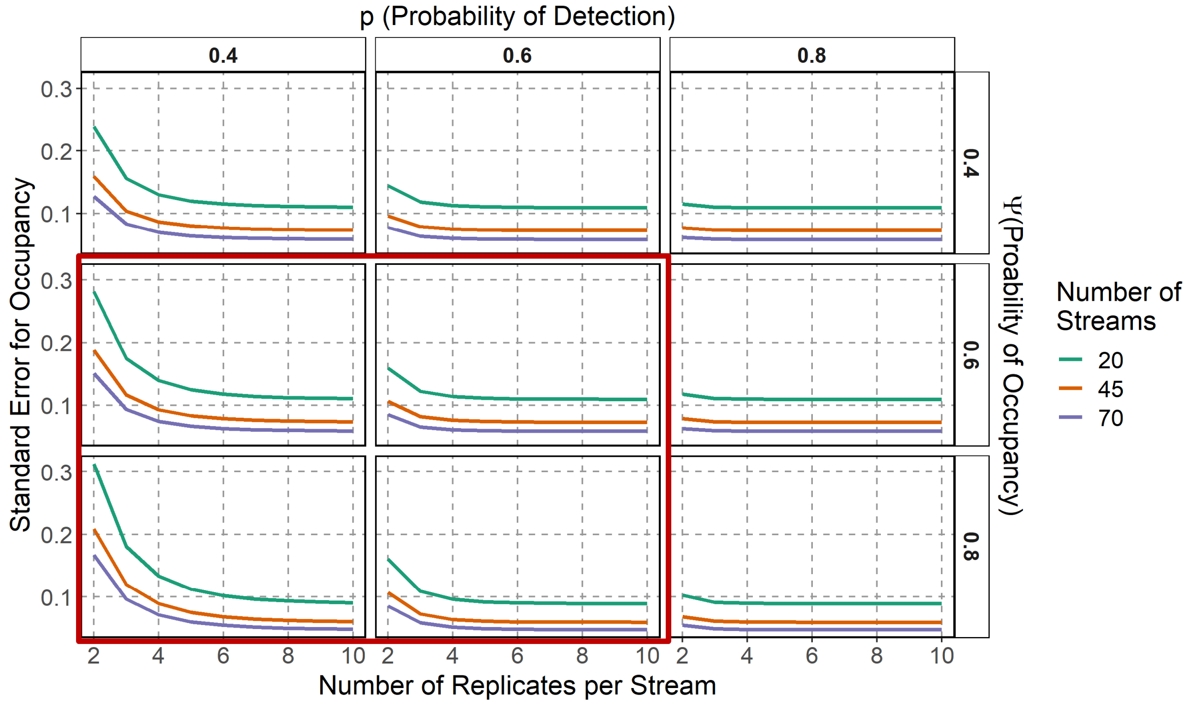


Figure 5. Changes in the standard error of occupancy probability estimates based on the number of study streams relative to the number of within-stream replicates for various detection and occupancy probabilities. The numbers of streams and replicates were selected based on the expected ranges of detection and occupancy probabilities (Artym 2016, red box), in an attempt to minimize standard error.

Since spatial replicates within a stream are spaced sequentially, it is possible that detection of the species in one replicate is not independent of the detection of the species in a neighbouring replicate. Using a similar study design, Baker et al. (2017) found that if YOY were detected at an upstream replicate, there was an increased probability of YOY detection in the neighbouring downstream replicate. This violation can be mitigated by expanding the static, single-season occupancy model to incorporate variables that account for correlated detections (Hines et al. 2010; MacKenzie et al. 2018). The need to account for correlation here was assessed by comparing results from single-season and correlated detection models.

2.2.2 Presence/absence surveys

Presence or absence of YOY Arctic Grayling was assessed using streamside visual surveys, which previous research has shown to be an effective and efficient technique in Barrenland streams (Baker et al. 2017). Surveys were completed during the YOY rearing period, within 23 consecutive days extending 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). Two surveyors started on opposite ends of the most downstream replicate of a site, and walked along the streambank while visually searching for YOY Arctic Grayling. No restrictions were placed in terms of search method, and each team member was free to move about the replicate as they deemed fit, including entering the stream if desired. After three minutes had elapsed, surveyors paused to confirm if either had a positive detection. If both had observed YOY Arctic Graying, the survey was complete. If one or neither had observed YOY, the survey continued until eight minutes had elapsed, at which point the survey was considered complete, regardless of detection. A maximum survey duration of eight minutes provided sufficient time to effectively search a 30 m segment of stream. Following completion of the survey, presence/absence of YOY Arctic Grayling, count of YOY detected, time to first detection, search duration, and incidental observations of other species within the replicate were recorded. The process was then repeated at the adjacent upstream replicate. Survey team members remained consistent throughout the entire sampling period.

2.2.3 Covariate data collection

The most basic occupancy model assumes that detection and occupancy probabilities remain constant across replicates and sites, respectively. Violation of these assumptions was expected in this study. The probability of detecting Arctic Grayling in a replicate, given presence, was anticipated to be influenced by instream (e.g., water depth) and other environmental variables (e.g., percentage of sunlight/cloud cover during the survey). 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 is 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. Consistent with established approaches (MacKenzie et al. 2018), variables thought to influence the probability of detection were collected at each replicate, whereas variables thought to influence the probability of occupancy were collected at each site. It is possible that a single variable may influence both probability of detection and probability of occupancy. For example, high water velocity may reduce visual detection probability, as well as reduce suitability of habitat for YOY and occupancy probability. In these instances, covariate data collected at the scale of 30 m replicates were used to model detection, and then averaged (arithmetic mean) across all replicates within a site to model occupancy. A summary of covariates and method of collection is provided in Table 2.

Table 2. Summary of covariate data collected to account for potential heterogeneity in detection and occupancy probability, and their method of collection.

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

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 replicate along a transect running perpendicular to the stream flow. Transect and measurement locations were selected to capture a representative range of the depth/velocity conditions present. This transect was also used to measure total stream width (leftmost wetted edge to rightmost 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). A minimum of 20 evenly-spaced, vertical depth/velocity measurements were collected if stream width permitted. For narrow streams, measurements were spaced a minimum distance of 0.1 m apart. All velocity measurements were taken at 0.6 of depth below the water surface.

Water temperature data were collected at each stream using a single TidbiT® V2 temperature logger set to record at 10-minute 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, in a location that was expected to remain below the water surface for the duration of the summer. Temperature loggers were installed between June 18 and 27, 2019, and were removed between August 29 and September 03, 2019. To ensure that the length of the temperature record for each stream was the same, temperature data files were trimmed to the time of last install and the time of first removal. Summary statistics were calculated for each stream, including daily mean, mean minimum, mean maximum, and mean coefficient of variation (CV), as well as accumulated thermal units (summation of all temperature records). Temperature data preparation and analysis were completed in R (R Core Team 2019).

*In situ w*ater quality covariate data were collected using calibrated hand-held meters. Dissolved oxygen (mg/L and % saturation) was collected using an OxyGuard Handy Polaris (OxyGaurd International A/S, Farum, Denmark), while pH and specific conductivity (µS/cm) 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, categorized using size classes (bedrock, boulder, cobble, etc. (Bain et al. 1985)) and organic material. 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 x 25 m resolution) by the Nunavut Department of Environment and Caslys Consulting (Campbell et al. 2012), and imported into QGIS (QGIS Development Team 2019). Study streams were digitized as linear segments, and a 10 m buffer (total width of 20 m) was applied to each stream. The relative percentage of upland and lowland land classes within the buffer were then calculated for each stream.

Lake polygon and watercourse data used to calculate the contributing upstream lake surface area, and were obtained from the National Hydro Network (Natural Resources Canada 2016a). Using QGIS (QGIS Development Team 2019), the surface areas of lakes within the study region were calculated. 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).

2.3 Statistical analysis

2.3.1 Data preparation

As an initial investigative tool, individual bar plots were generated for each occupancy covariate; each bar represented an individual stream. Streams were placed in ascending order of the covariate (if continuous) and a colour was assigned to each stream, representing either detection or non-detection of YOY Arctic Grayling. This allowed for a preliminary assessment of the strength and nature (e.g., linear, square root, quadratic) of relationships between each covariate and the probability of occupancy.

Prior to constructing occupancy models, continuous covariates in detection and occupancy datasets were standardized (z-score) and assessed for collinearity using Pearson correlation coefficients (pair-wise comparisons). Covariates with a correlation coefficient with an absolute value of greater than 0.5 were not included in the same model, as this can lead to difficulties in interpreting the specific contributions of the correlated variables (Gotelli and Ellison 2013), and potentially lead to misinterpretation of model results.

2.3.2 Occupancy model construction and selection

Single-season occupancy models were constructed in R (R Core Team 2019), using the RPresence package (MacKenzie, and Hines 2019). Construction of occupancy models is divided into two components: modeling variables that affect the probability that YOY are detected at a replicate, and modeling variables that affect the probability that YOY are present at a site (stream, in this study). Careful consideration of how each variable affects detection and occupancy is important during model construction, as certain variables have the potential to affect both probabilities (e.g., velocity). Following recommended practice, the occupancy portion of the model was constructed first, while leaving the probability of detection constant (MacKenzie et al. 2018). This was done because modeling the detection probability while holding occupancy constant may lead to an overestimation of the influence of factors on detection or, conversely, lead to an underestimation of the true effect of the variable on occupancy and detection if the effects are opposite (MacKenzie et al. 2018).

Covariates that showed potential explanatory power in the investigative plots (see Section 2.3.1) were selected from the *a priori* list of covariates collected for inclusion in candidate models. The potential for interactions between variables was carefully considered in addition to the diagnostic plots (e.g., stream slope may have an increased influence on the presence/absence of YOY for small discharge streams), as these relationships are more difficult to identify. Due to the small number of study sites (n=49), a maximum of three occupancy covariates were included in any one *a priori* model to avoid overparameterization (Anderson 2008). Detection covariates were then incorporated into top candidate occupancy models. It can be difficult to visually assess the effect of a covariate on the probability of detection, as sites with perfect detection, imperfect detection, and no detections should be considered. For instance, if YOY were not detected in any of the five replicates at a site, it is possible that the site was unoccupied, or that the site was occupied but YOY remained undetected. It is conceivable that a detection variable may have enough influence on detection probability that it prevents detection at all replicates within a site. Therefore, each of the detection covariates was considered for inclusion in candidate models.

Candidate models were assessed using Akaike's Information Criterion (AIC). AIC encourages parsimonious models, as better scores are generated for models that minimize information lost while using as few covariates as possible (MacKenzie et al. 2018). However, with a relatively small sample size (five replicates at 49 streams) there is potential for model overparameterization (Anderson 2008). This can be mitigated by incorporating an additional bias correction term into the AIC score, known as AICc (Anderson 2008). The correction term is based on the 'effective' sample size, which can be difficult to define for occupancy modeling, as sample size differs between occupancy and detection probabilities (i.e., total number of replicates vs. total number of sites). Following Baker et al. (2017), the number of sites was selected as the 'effective' sample size for this study.

Constructed models were compared based on their relative difference in AICc values (ΔAICc), model weights, and evidence ratios (Anderson 2008). Model coefficients (β coefficients) and their standard errors, along with deviance (-2loglikelihood , or -2*l*) were examined to identify pretending variables (Anderson 2008). If the standard error of the β coefficient overlapped zero, the covariate was considered to be uninformative and was removed from the model (Leroux 2019). Pretending variables are also usually within two AICc if each other, with a nearly identical deviance.

2.3.3 Assessing model fit

2.3.3.1 Detection probability

It is important to demonstrate that the fitted model accurately describes the observed data (MacKenzie and Bailey 2004). Using AIC to select the best model within a candidate set of models does not ensure the selection of a good model, and it is essential to confirm that models are realistic and explain variability in the data (MacKenzie et al. 2018). One method of assessing model fit is to compare the variance of the model with the observed variance of the data. If there is greater variability in the observed data relative to the model, the data are overdispersed (Anderson 2008). In occupancy modeling, overdispersion can occur for several reasons, including non-independent observations or structural inadequacies in the model (e.g., missing covariates, abundance-induced detection heterogeneity) (MacKenzie et al. 2018).

MacKenzie and Bailey (2004) identified a method for assessing the fit of single-season occupancy models. A Pearson's chi-square test is used to assess whether the observed detection history at each site has a reasonable chance of occurring if the model is assumed to be correct (MacKenzie et al.

2018). One of the difficulties of assessing model fit using this method is that the number of potential detection histories increases exponentially with the number of replicates, and with a comparatively small number of sites, the probability of any one detection history occurring becomes increasingly small. For this study, there are 32 possible detection histories (five replicates, therefore 2^5 unique histories), with only a total of 49 sites visited. To overcome this limitation, MacKenzie and Bailey (2004) developed a parametric bootstrapping procedure to determine whether the observed chi-squared statistic is unusually large. By comparing the chi-square test statistic for the observed data, X_{Obs}^2 , to the average of the test statistic for the parametric bootstrap, $\bar{\mathrm{X}}_B^2$, an overdispersion parameter, $\hat{c}$, can be estimated using:

$$\hat{c} = {\mathrm{X}_{Obs}^2}/{\bar{\mathrm{X}}_B^2}$$

Overdispersion parameters of one indicate good fit of the data, those greater than one are said to be overdispersed (more variation in the observed data than expected by the model), and those less than one are underdispersed (less variation in the observed data than expected by the model) (MacKenzie et al. 2018). If overdispersion is believed to be due to a lack of independent observations, an additional penalty term can be added to the AIC score (quasi-AIC, or QAIC) to adjust for the degree of dependence reflected in the data (Anderson 2008). If overdispersion is due to other structural inadequacies, alternative model types or the inclusion of alternative variables can be considered.

2.3.3.2 Occupancy probability

The goodness of fit test developed by MacKenzie and Bailey (2004) uses the detection history to assess model fit, and therefore cannot identify violations in the occupancy component of the model (MacKenzie and Bailey 2004; Warton et al. 2017). In this study, there was an opportunity to assess model fit for occupancy using data previously collected from additional streams within the study area. Fish sampling and habitat assessments have previously been conducted in numerous streams within the study area during baseline environmental assessments for construction projects (e.g., all weather access road, open pit mine). While there is some overlap in the streams that were sampled during baseline assessments and those that were included in this study (particularly in the southern portion of the study area), there are 16 streams from past surveys that were not used to construct the occupancy model. This provided a unique opportunity to build a test data set and use it to assess the accuracy of the occupancy model in predicting occupancy of new streams within the region.

The independent test data set was constructed from multiple sources, including 2016 spring (late June) electrofishing surveys, which targeted adult Arctic Grayling spawning in streams (C. Portt and Associates 2018). While the focus of this occupancy study is on YOY, the presence of spawning adults in streams in late June is a good indicator of suitable spawning habitat and, given the strong site fidelity of Arctic Grayling during spawning and summer feeding (Northcote 1995; Deegan et al. 1999; Buzby and Deegan 2000), it is also evidence of suitable rearing conditions for YOY. In total, six of these streams were incorporated into the test data set.

Spring and summer (June – September) sampling of streams surrounding the Amaruq mine site prior to development yielded an additional three streams that could be incorporated into the test data set. A variety of sampling methods were used to assess presence/absence of species within these streams, including electrofishing, minnow trapping, and stream gill net deployments (C. Portt and Associates 2018). Finally, an additional seven streams along the all-weather access road from Meadowbank to Amaruq (Figure 3), were electrofished in the spring/summer prior to road construction (C. Portt and Associates 2015), and were included in the test data set.

2.4 Comparison to other YOY studies

By comparing the results found in this study (near Baker Lake) to other studies completed in the Arctic/sub-Arctic, factors influencing habitat suitability of YOY Arctic Grayling across different northern landscapes can be identified and compared. Two studies assessing the habitat use of Barrenland populations of YOY Arctic Grayling in the NWT have been completed to date (Jones and Tonn (2004) and Baker et al. (2017)), and an additional occupancy study of YOY Arctic Grayling was completed in the mountainous sub-Arctic tributaries of the Little Nahanni River, along the border of the NWT and Yukon (Lewis 2018). Jones and Tonn (2004) studied microhabitat preferences of YOY in one Barrenland stream by sampling habitat use of individual YOY and modeling results as resource selection functions, whereas Baker et al. (2017) developed occupancy models based on YOY presence/absence surveys and habitat data in nineteen Barrenland streams. Part of the Baker et al.

(2017) study included assessment of numerous streams prior to and following loss of connectivity (cofferdam installation) and flow augmentation as a result of mining activities. The comparison with this present study was limited to 15 streams in two watersheds that were not affected by flow augmentation, and used supplemental data from Artym (2016) and Baker et al.(2017). The author of the Nahanni study assessed 35 randomly selected 'patches' within four sub-watersheds and, similar to this study, used a static single-season occupancy model to investigate habitat variables that were related to presence/absence of YOY Arctic Grayling (Lewis 2018). Supplemental habitat covariate data from Lewis (2018) were used to compare stream conditions and occupancy of YOY Arctic Grayling within mountain environments to results from the Barrenlands. Study designs for these four projects (Jones, Baker, Lewis, and this study) differed due to specific research objectives and landscape, yet the fundamental goal of assessing how habitat variables influence the presence/absence of Arctic Grayling YOY within streams makes an inter-study comparison of results informative.

3.Results

3.1 Presence/absence surveys

Arctic Grayling YOY were detected in 33 of 49 surveyed streams, resulting in a naïve occupancy estimate of 0.67 (naïve occupancy assumes perfect detection). In the 33 streams where YOY were detected, the overall probability of detection was high (Figure 6). Arctic Grayling YOY were detected in 135 of 165 replicates (detection probability of 0.82). Detection was perfect in twenty (61%) streams (i.e., YOY observed in all five replicates). In two (6%) streams YOY were detected in four of five replicates, in four (12%) streams YOY were detected in three of five replicates, in five (15%) streams YOY were detected in two of five replicates, and in two (6%) streams YOY were detected in one of five replicates. A summary of detection histories for all sites is presented in Figure 6.

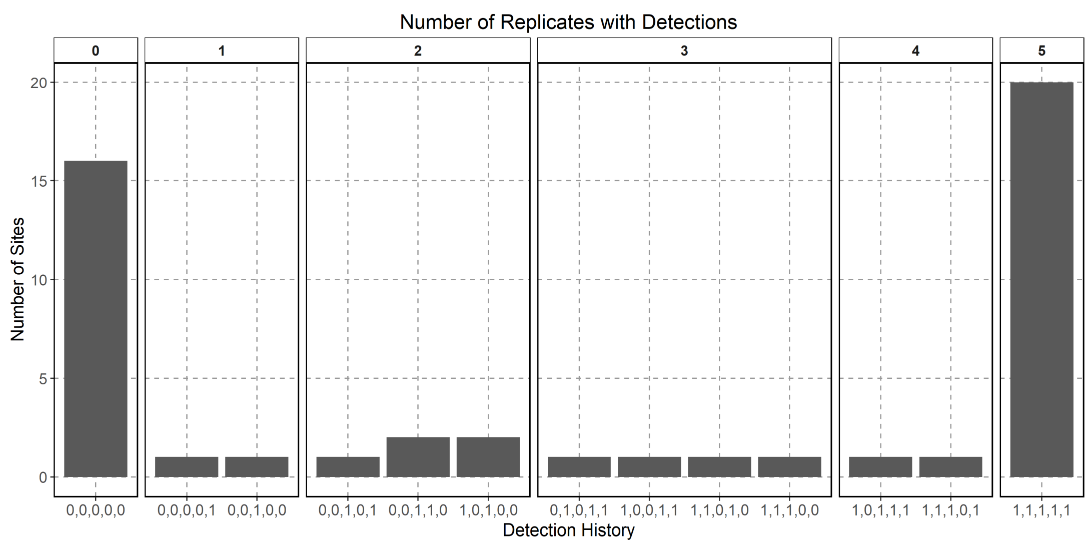


Figure 6. A summary of detection histories for all study streams. 0 indicates absence of young-of-year Arctic Graying at a replicate, whereas 1 indicates presence of young-of-year Arctic Grayling at a replicate. Replicates are ordered from downstream to upstream.

3.2 Selection of model type

Prior to the construction of occupancy models that incorporated detection and occupancy covariates, a comparison was made between static single-season and single-season correlated detection null models (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 single-season correlated detection model failed to converge, suggesting that sequential spatial replicates were not autocorrelated. As a result, all candidate models were constructed using the static single-season occupancy equation (MacKenzie et al. 2018).

3.3 Detection

3.3.1 Detection covariates

Variables that may explain imperfect detection of YOY were collected at each replicate. A summary of the total observed range for each of these variables (detection covariates) is presented in Table 3, as well as observed ranges for replicates where YOY were and were not detected. For analysis purposes, time of day was converted to time elapsed since 8:00 AM (number of minutes) and was treated as a continuous variable. Detection variables that were correlated and had an absolute correlation coefficient value greater than 0.5 are presented in Table 4; all pairwise correlations for continuous detection variables are provided in Appendix B.

Table 3. Comparison of the range of observations for each detection variable for all replicates, occupied replicates, and unoccupied replicates.

Variable	Units	All Replicates (n = 245)	Occupied Replicates (n = 132)	Unoccupied Replicates (n = 113)
Sample Date	-	16 July - 07 August	16 July - 07 August	17 July - 07 August
Time of Day	hh:mm	08:10 - 18:02	08:10 - 17:50	08:33 - 18:02
Cloud Cover	%	0-100	0-100	0-100
Rain	intensity	None - Heavy	None - Heavy	None - Moderate
Bedrock	%	0-35	0-20	0-35
Boulder	%	0-100	5-100	0-100
Cobble	%	0-65	0-65	0-60
Gravel	%	0-50	0-40	0-50
Sand	%	0-35	0-25	0-35
Fines	%	0-5	0-5	0-5
Organics	%	0-100	0-60	0-100
Slope	%	0.5-10.5	0.5-5.2	0.7-10.5
Instream Vegetation	%	0-70	0-35	0-70
Overhanging Vegetation	%	0-90	0-90	0-70
Undercut Bank	%	0-75	0-70	0-75
Average Depth	m	0.036-0.528	0.036-0.528	0.042-0.482
Average Velocity	m/s	0.008-0.736	0.008-0.702	0.018-0.736

Table 4. Summary of correlated detection variables, where Pearson's r correlation coefficient was greater than an absolute value of 0.5.

Variable 1	Variable 2	Pearson's r
% Organic	% Instream Vegetation	0.70
% Organic	% Boulder	-0.64
% Cobble	% Gravel	0.61

3.3.2 Detection model results

Each of the detection covariates was considered for inclusion in candidate models. Depth and velocity were the only two detection variables with a better AICc score than the null model, indicating that depth and velocity provide some explanation for imperfect detection (Table 5). The highest ranked model included an interaction between depth and velocity, but there was also support for an additive model, as evidenced by AICc (Table 5). An examination of regression coefficients (Table 8) reveals that increases in depth and velocity decreased the likelihood of YOY being detected, which is intuitive given that fish were detected using visual surveys and fish are more difficult to see at 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 waters.

Table 5. Summary of detection models for visual surveys of Arctic Grayling young-of-year in Barrenland streams. To allow for a direct comparison, the same model for occupancy probability was used for all candidate detection models.

Model	AICc	ΔAICc	-2l	Weight	Evidence Ratio	Coefficient Estimates (±SE)			
						Intercept	Depth	Velocity	Depth*Velocity
$p(Depth * Velocity)$	175.54	0.00	158.74	0.43	1.00	1.60 (0.22)	-0.42 (0.21)	-0.32 (0.22)	-0.31 (0.20)
$p(Depth + Velocity)$	175.90	0.37	161.85	0.36	1.20	1.56 (0.22)	-0.42 (0.19)	-0.44 (0.19)	-
$p(Velocity)$	178.29	2.75	166.86	0.11	3.95	1.54 (0.22)	-	-0.51 (0.19)	-
$p(Depth)$	178.56	3.02	167.13	0.09	4.53	1.51 (0.21)	-0.48 (0.18)	-	-
$p(\cdot)$	183.21	7.68	174.28	0.01	46.68	1.47 (0.20)	-	-	-

3.3.3 Assessment of model fit

To assess model fit, a Pearson's chi-squared (χ^2) test comparing observed and parametric bootstrapped data was used to determine if the observed detection history at each site had a reasonable chance of occurring, assuming the model was correct (MacKenzie et al. 2018). A comparison of the χ^2 test statistics yielded a $\hat{c}$ value of 3.4, suggesting the model is overdispersed. Further examination of the data and χ^2 test statistics indicated that higher than expected variance in the data was largely due to an unexpectedly high number of sites with low detection probability (Table 6). Parametric bootstrapping results predict a low likelihood of a site having only one replicate with a detection (i.e., YOY detected in one of five replicates), yet this occurred at 2 of 49 sites. Having a site with two detections (i.e., YOY detected in two of five replicates), is also expected to be unlikely, yet this occurred at four sites. In fact, two of the four sites had the exact same detection history (YOY detected in replicate three and four only), an exceedingly unlikely event given the number of possible detection history combinations. These six sites with unexpectedly low detection probability greatly inflated the test statistic.

Table 6. Summary of χ^2 test statistic for the observed and expected number of sites with each detection history.

Detections per Site	History	Observed # of Sites	Expected # of Sites	χ^2
0	0,0,0,0,0	16	16.00	0
1	0,0,0,0,1	1	0.04	21.92
	0,0,1,0,0	1	0.05	17.04
2	1,0,1,0,0	1	0.13	5.72
	0,0,1,1,0	2	0.14	24.69
	0,0,1,0,1	1	0.23	2.65
3	1,1,1,0,0	1	0.57	0.31
	1,1,0,1,0	1	0.41	0.84
	1,0,0,1,1	1	0.36	1.15
	0,1,0,1,1	1	0.55	0.37
4	1,1,1,0,1	1	2.99	1.33
	1,0,1,1,1	1	2.02	0.52
5	1,1,1,1,1	20	11.65	5.99

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. It is unlikely that the overdispersion resulted from non-independent observations, as the correlated detection model failed to converge (Section 3.2). Rather, the higher than expected number of sites with both low and high detection probabilities supports the notion that there is unmodeled heterogeneity in detection probability. Since overdispersion was not attributed to non-independent observations, a correction to the AIC scores (QAIC) was not applied (MacKenzie et al. 2018).

One possible cause of unmodeled heterogeneity in detection probability is the relative difference in abundance of YOY between streams. The differences in YOY abundance among stream can result in differences in detection probabilities. If abundance was not correlated with any detection covariates that were collected, then the heterogeneity remains unmodeled. A comparison of the observation rate (number of YOY observed per minute) during presence/absence surveys at each stream shows a pattern of decreased observation rate with a decrease in the number of replicates with detections (Figure 7); high observation rates occurred at sites with perfect detection, and low observation rates occurred at sites with imperfect detection. A higher observation rate is likely the result of an increased number of YOY within the site, suggesting that relative differences abundance of YOY Arctic Grayling between sites, which are unaccounted for in the model, led to higher than expected variance.

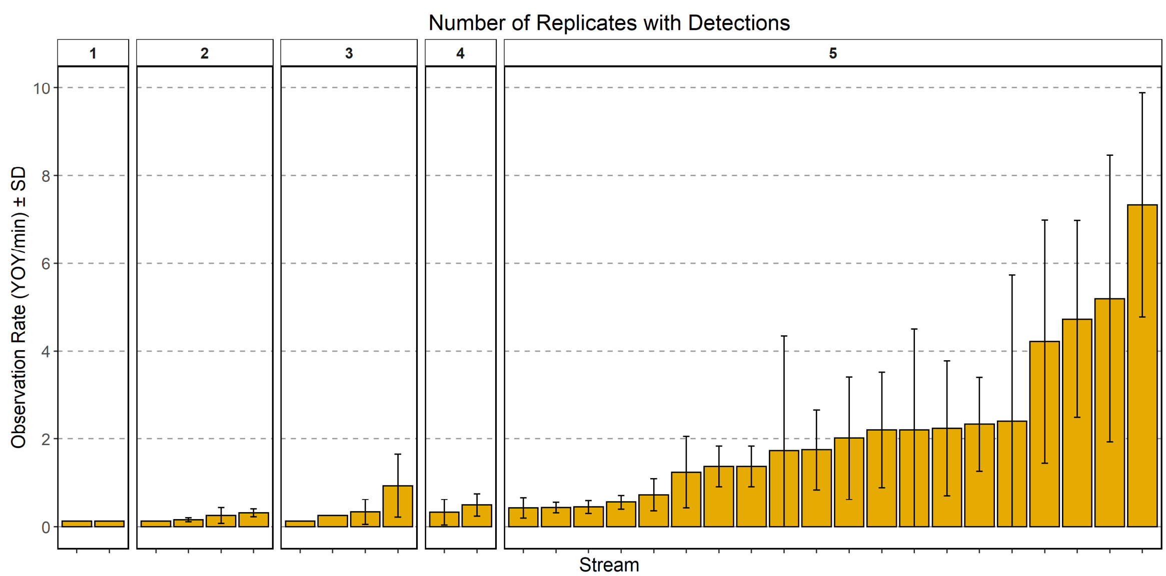


Figure 7. Average detection rate (number of YOY observed/min) for each occupied stream based on the number of replicates with detections. The overall trend of decreasing observation rate with fewer replicates with detections suggests that variation in abundance among streams influences detection probability.

3.4 Occupancy

3.4.1 Occupancy covariates

Occupancy variables (identified in Table 2) were either collected at each replicate and averaged for the site (if also considered to affect detection probability), or collected at one representative location per site (if thought to only affect occupancy probability). Covariate data were successfully collected for each stream, with one exception where land classification data could not be determined from satellite imagery due to substantial cloud cover obscuring the stream and surrounding habitat. Since occupancy modeling demands that covariate data be available for all sites included in the model, this stream could not be included, reducing the sample size to 48 sites. A summary of the total observed range for each occupancy variable is presented in Table 7, as well as the observed ranges for sites where YOY were and were not detected. Occupancy variables that were correlated and had an absolute correlation coefficient value greater than 0.65 are presented in Table 8; all pairwise correlations for continuous occupancy variables are provided in Appendix B.

Table 7. Comparison of the observed ranges of measurements of each occupancy variable for all sites, occupied sites, and unoccupied sites.

Category	Variable	Units	All Sites (n = 49)	Occupied Sites (n = 33)	Unoccupied Sites (n = 16)
Substrate	Bedrock	%	0 - 8	0 - 7	0 - 8
	Boulder	%	0 - 100	14 - 96	0 - 100
	Cobble	%	0 - 47	4 - 47	0 - 34
	Gravel	%	0 - 34	0 - 34	0 - 31
	Sand	%	0 - 11	0 - 11	0 - 10
	Fines	%	0 - 1	0 - 1	0 - 0
	Organics	%	0 - 100	0 - 42	0 - 100
Vegetation	Instream Vegetation	%	0 - 65	0 - 30	0 - 65
	Overhanging Vegetation	%	0 - 57	0 - 57	0 - 50
Geomorphology	Undercut Banks	%	0 - 45	0 - 45	0 - 2
	Mean Depth	m	0.08 - 0.36	0.08 - 0.36	0.08 - 0.32
	Mean Velocity	m/s	0.02 - 0.58	0.02 - 0.58	0.04 - 0.48
	Discharge	m^3/s	0.004 - 5.040	0.016 - 5.040	0.004 - 0.601
	Wetted Width	m	0.8 - 79.0	1.0 - 79.0	0.8 - 60.2
	Number of Channels	-	1.0 - 5.2	1.0 - 5.2	1.0 - 4.2
	Slope	%	0.7 - 6.6	0.7 - 4.1	1.0 - 6.6
Water Quality	Dissolved Oxygen	mg/L	9.16 - 11.90	9.16 - 11.90	9.21 - 11.70
	Dissolved Oxygen	% Saturation	91.8 - 110.3	92.4 - 106.1	91.8 - 110.3
	pH	pH units	5.70 - 7.89	6.35 - 7.89	5.70 - 7.55
	Specific Conductivity	µS/cm	13.1 - 110.7	13.2 - 94.9	13.1 - 110.7
Water Temperature	Mean Daily Min	°C	7.98 - 11.54	9.07 - 11.54	7.98 - 11.01
	Mean Daily Max	°C	12.56 - 17.22	12.55 - 15.44	12.70 - 17.22
	Mean Daily Range	°C	1.58 - 8.62	1.58 - 5.46	1.98 - 8.62
	Mean Daily C.V.	°C	4.63 - 23.65	4.63 - 14.95	5.49 - 23.66
	ATU	°C	97,260 - 114,875	97,260 - 114,875	97,334 - 113,808
Landscape Variables	Contributing Upstream Lake Area	km^2	0.01 - 29.04	0.33 - 29.04	0.01 - 3.73
	Land Classification	% Lowland	13 - 100	67 - 100	13 - 100

Table 8. Summary of correlated occupancy variables that had Pearson's r correlation coefficients greater than an absolute value of 0.65. Strong correlations were also observed between water temperature metrics (not shown).

Variable 1	Variable 2	Pearson's r
Discharge	Contributing Upstream Lake Area	0.87
% Organic	% Instream Vegetation	0.74
% Organic	Mean Daily Temperature Range	0.74
% Organic	Mean Daily Temperature CV	0.71
% Organic	Mean Daily Max Temperature	0.65
% Organic	% Boulder	-0.67
% Cobble	% Gravel	0.71

3.4.2 Potential explanatory variables for occupancy

Investigative plots revealed several variables that potentially influenced the probability of a site being occupied by YOY Arctic Grayling: substrate, land classification, slope, and contributing upstream lake area.

3.4.2.1 Substrate

Visual inspection of plots revealed that size classes of inorganic substrates (e.g., cobble, boulder, gravel) were not related to stream occupancy. However, the relative percentage of inorganic substrate (regardless of size class) to organic substrate showed a relationship with occupancy; as the % inorganic substrate increased, occupancy increased (Figure 8). The relationship did not appear to be linear. Instead, a square-root relationship was hypothesized (MacKenzie et al. 2018); 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. This non-linear relationship between substrate and occupancy is best represented as the square-root of % inorganic material.

The relative percentage of inorganic to organic substrate was correlated with other occupancy covariates. Although % inorganic substrate was used as the predictor variable in the occupancy models, interpretation is more intuitive when considering the inverse, % organic substrate. There was a strong, positive correlation between % organic substrate and water temperature metrics, including mean daily temperature range ($r = 0.74$) and mean daily max temperature ($r = 0.65$) (Table 5). This suggests that streams with higher % organic substrate had greater diurnal fluctuations in water temperature, with higher daily maximum temperatures than those that were dominated by inorganic substrate. Organic substrate was also positively correlated with instream vegetation ($r = 0.74$, Table 5). Investigative plots suggest that the relative percentage of inorganic to organic substrate was a better predictor of occupancy than either water temperature or instream vegetation covariates, and therefore was selected for consideration in final occupancy models.

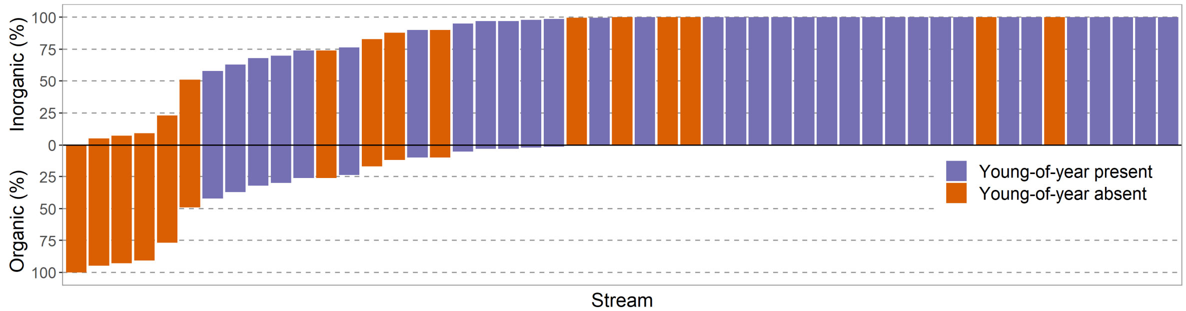


Figure 8. Relationship between substrate and stream occupancy. Each bar represents a site (individual stream). Orange bars indicate streams where young-of-year Arctic Grayling were not detected, and purple bars indicate streams where they were detected, suggesting that streams with low percentages of inorganic substrate (high percentages of organic substrate) were less likely to be occupied.

3.4.2.2 Land classification

Most of the study streams were dominated by lowland land cover, and YOY were detected in many of the lowland-dominated streams; the relationship between land classification and occupancy is shown in Figure 9. Stream occupancy by YOY Grayling was lower in streams with a higher proportion of upland land cover. The relationship between land classification and occupancy probability closely resembled that of substrate, where small increases in % lowland land cover had a greater effect on the probability of occupancy when % lowland was low, and a lesser effect on the probability of occupancy when % lowland was high. As a result, land classification was represented in models as the square-root of % lowland land cover.

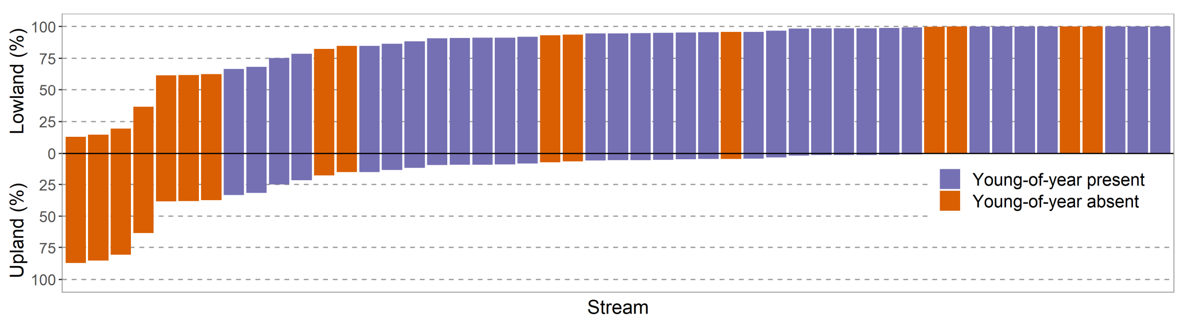


Figure 9. Relationship between land classification and stream occupancy. Each bar represents a site (individual stream). Orange bars indicate streams where young-of-year Arctic Grayling were not detected, and purple bars indicate streams where they were detected, suggesting that streams with low percentages of lowland land cover were less likely to be occupied.

3.4.2.3 Slope

The average slope of surveyed sites varied from 0.7 % to 6.6 %. YOY Arctic Grayling were not detected in the six streams where slopes exceeded 4.1%, suggesting that as stream slope increases, the probability that the stream is occupied decreases (Figure 10). Stream slope was included in candidate models as a linear relationship (untransformed).

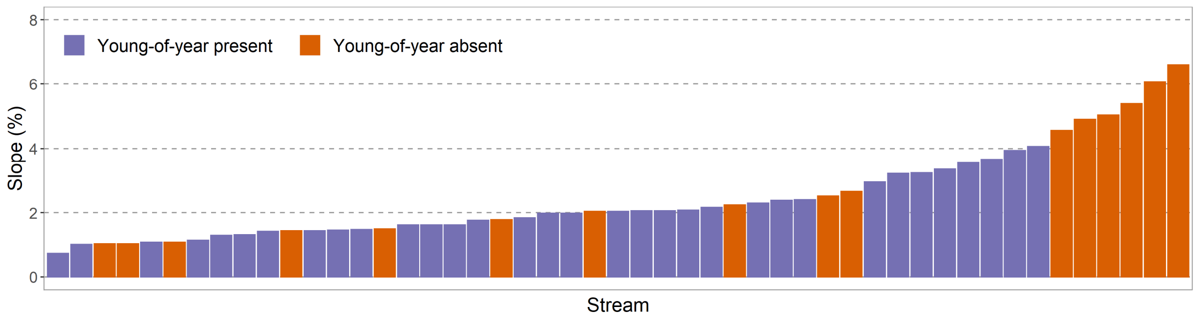


Figure 10. Relationship between slope and stream occupancy. Each bar represents a site (individual stream). Orange bars indicate streams where young-of-year Arctic Grayling were not detected, and purple bars indicate streams where they were detected, suggesting that streams with high slopes were less likely to be occupied.

3.4.2.4 Contributing upstream lake area

The cumulative surface area of lakes upstream of a site varied considerably among study streams (0.01 km² - 26.5 km²). A non-linear, threshold relationship between upstream lake surface area and stream occupancy was apparent (Figure 11). Without sufficient upstream lake surface area contributing to a stream, it was unlikely to be occupied. YOY were not detected in any of the ten streams with upstream contributing lake area less than 0.33 km². The likelihood that a stream was occupied increased considerably beyond ~0.33 km². A $\log_{10}$ transformation was applied to this variable in candidate models. Contributing upstream lake area was positively and significantly correlated with stream discharge (r = 0.87, Table 8), suggesting that upstream lakes provide an important source of water for streams. Although not strongly correlated, many of the streams with very low contributions of upstream lake area were also found to have high % organic substrate (r = -0.28, Appendix B), and the six streams with the highest % organic substrate all had contributing upstream lake areas of < 0.33 km².

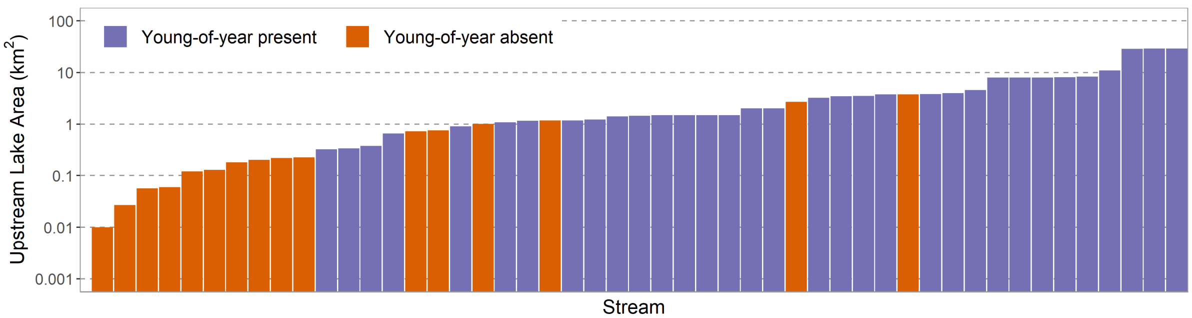


Figure 11. Relationship between contributing upstream lake area ($\log_{10}$ scale) and stream occupancy. Each bar represents a site (individual stream). Orange bars indicate streams where young-of-year Arctic Grayling were not detected, and purple bars indicate streams where they were detected. Streams were less likely to be occupied when upstream contributing lake area was smaller.

3.5 Occupancy model results

Covariates included in candidate models for occupancy were limited to the four variables identified in Section 3.4.2 : % lowland, % inorganic substrate, slope, and upstream lake area. Candidate models were ranked according to AICc (Table 9), and models with the standard error of one or more β coefficient overlapping 0 were identified as having pretending variables and removed from consideration (not shown in Table 9, see Appendix C for details). A comparison of the ΔAICc values shows a clear top model (Table 9). Land classification (% lowland) and contributing upstream lake area were the best predictors of whether a stream was likely to contain YOY Arctic Grayling. Regression coefficients (on the logit scale) show the magnitude and direction of the effect of the covariate on the probability of occupancy, ($\hat{\psi}$) (MacKenzie et al. 2018). For the top model, this can be written as:

$$logit(\hat{\psi}) \; = \; \beta_0 + \beta_1 \times \sqrt{Lowland\,\%} + \beta_2 \times log(Upstream\ Lake\ Area)$$

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

Table 9. Summary of candidate occupancy models for Arctic Grayling young-of-year in Barrenland streams.

Model[1]	AICc	ΔAICc	-2l	Likelihood	Weight	Evidence Ratio
$\psi\left(\sqrt{Lowland\,\%} + \log(Upstream\ Lake\ Area)\right)$	175.54	0.00	158.74	1.00	0.98	1
$\psi\left(\sqrt{Lowland\,\%} + \sqrt{Inorganic\,\%} + Slope\right)$	184.09	8.56	164.40	0.01	0.01	72
$\psi\left(\sqrt{Lowland\,\%} + \sqrt{Inorganic\,\%}\right)$	187.02	11.48	170.22	0.00	0	307
$\psi\,(\log(Upstream\ Lake\ Area))$	189.62	14.09	175.58	0.00	0	1091
$\psi\left(\sqrt{Inorganic\,\%} + Slope\right)$	199.10	23.57	182.30	0.00	0	-
$\psi\left(\sqrt{Lowland\,\%} + Slope\right)$	199.72	24.18	182.92	0.00	0	-
$\psi\left(\sqrt{Inorganic\,\%}\right)$	202.17	26.64	188.13	0.00	0	-
$\psi\left(\sqrt{Lowland\,\%}\right)$	202.22	26.68	188.17	0.00	0	-
$\psi\,(Slope)$	208.82	33.29	194.78	0.00	0	-
$\psi\,(\cdot)$	211.41	35.87	199.98	0.00	0	-
$\psi\,(\cdot)\ p\,(\cdot)$	219.78	44.24	215.52	0.00	0	-

[1] Probabilty of detection modelled as $p(Depth\ \times\ Velocity)$, with the exception of the null model, $\psi\,(\cdot)\ p\,(\cdot)$

The β-coefficients indicate that increases in lowland land classification and increases in contributing upstream lake surface area both increased the probability that a stream was occupied. Interpreting the effect of a covariate on occupancy probability can be difficult on the logit scale, however, as the relationship is non-linear. To visualize the effect of land classification on occupancy, values were converted to a probability scale; the probability of occupancy was calculated for % lowland values ranging from 0% - 100%, and contributing upstream lake area was held constant at the median observed value (1.43 km^2) (Figure 12). For streams where the landscape was dominated by uplands, there was a lower probability of YOY occupancy. The probability of occupancy increased as lowland landcover became increasingly dominant, and in streams where the landcover was exclusively lowland, there was a high probability that a stream contained YOY. Confidence intervals (95% CI) around the probability indicate higher confidence in predicting occupancy at high percentages of lowland land cover, and reduced confidence in predicting occupancy at moderate and low percentages of lowland land cover (Figure 12).

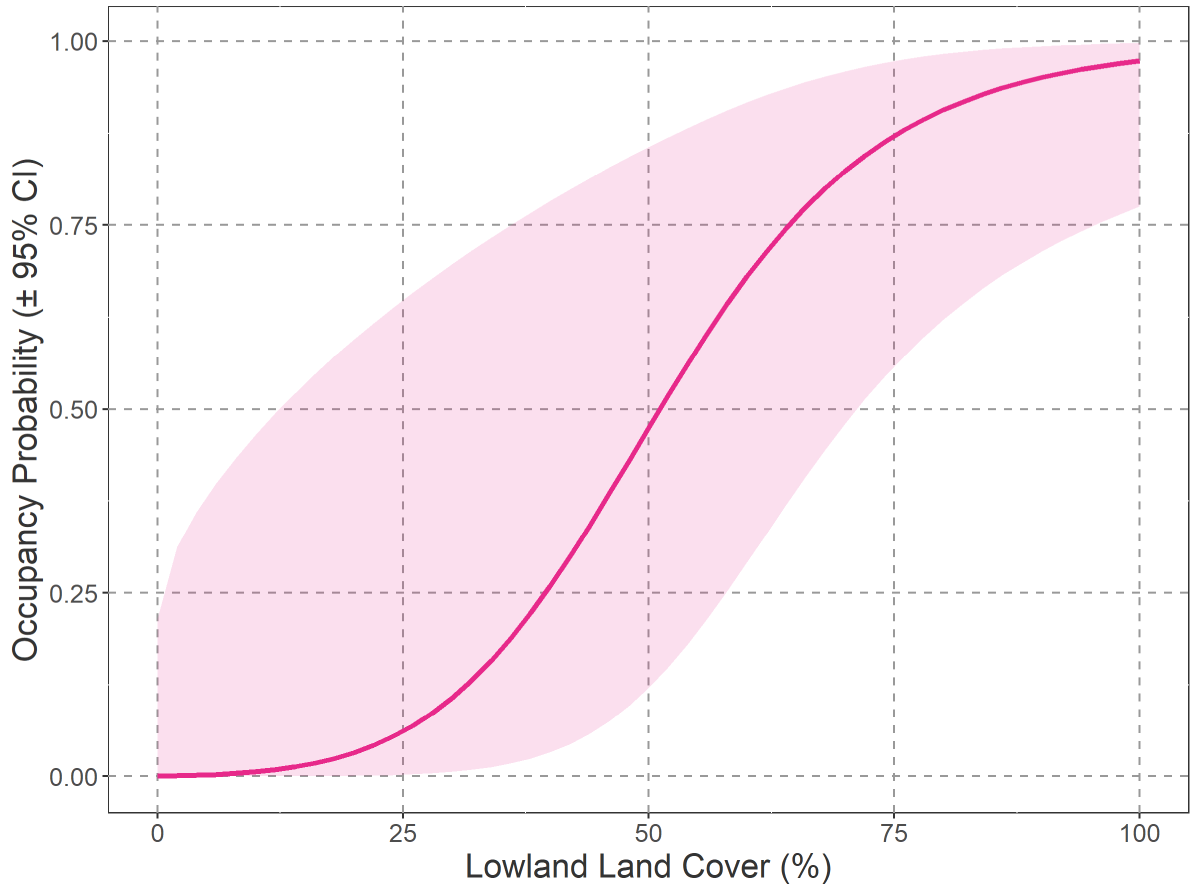


Figure 12. Relationship between land classification and probability of occupancy at the median value of contributing upstream lake (1.43 km²). Land classification is presented as the relative percentage of lowland land cover.

The relationship between contributing upstream lake surface area and occupancy was also converted to the probability scale to aid interpretation (percentage of lowland land cover was held constant at the median study stream value of 94.5%). The probability that a stream was occupied increased sharply from 0 to 0.8 as contributing upstream lake area increased from 0 km² to 1 km² (Figure 13). As contributing upstream lake area increased beyond 1 km², the 95% confidence interval narrowed, suggesting increasing confidence that a stream was occupied as upstream lake surface area increased.

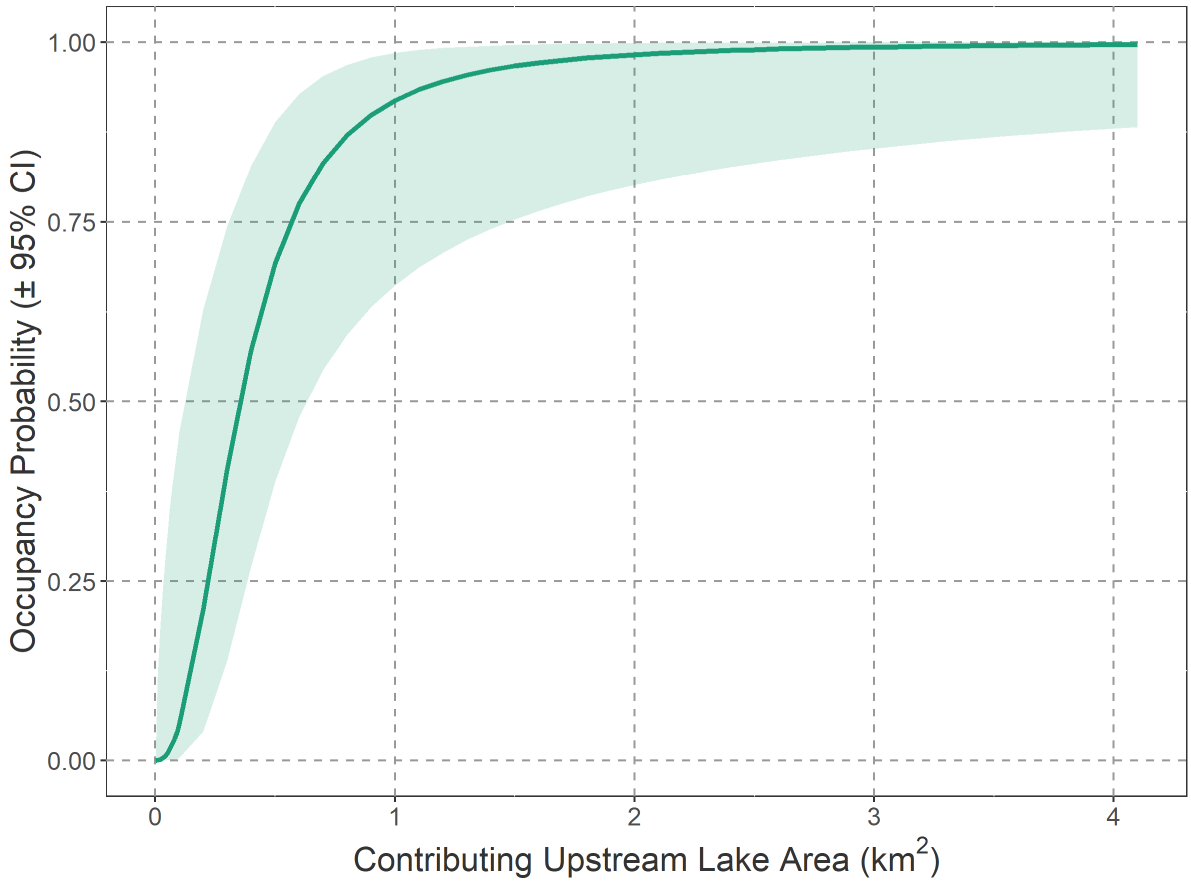


Figure 13. Relationship between contributing upstream lake area and the probability of occupancy at the median lowland land cover of 94.5%.

A bivariate plot of estimated occupancy as a function of both land classification and contributing upstream lake area illustrates that occupancy was highest when contributing upstream lake area and percentage of lowland land cover were both high (Figure 14). Some combinations of percentage lowland land cover and contributing upstream lake area are not represented in Figure 14 because streams with moderate to low percentages of lowland land cover and moderate to high contributing upstream lake area were not sampled. Given the random sampling design, it is likely these conditions are rare within the study area.

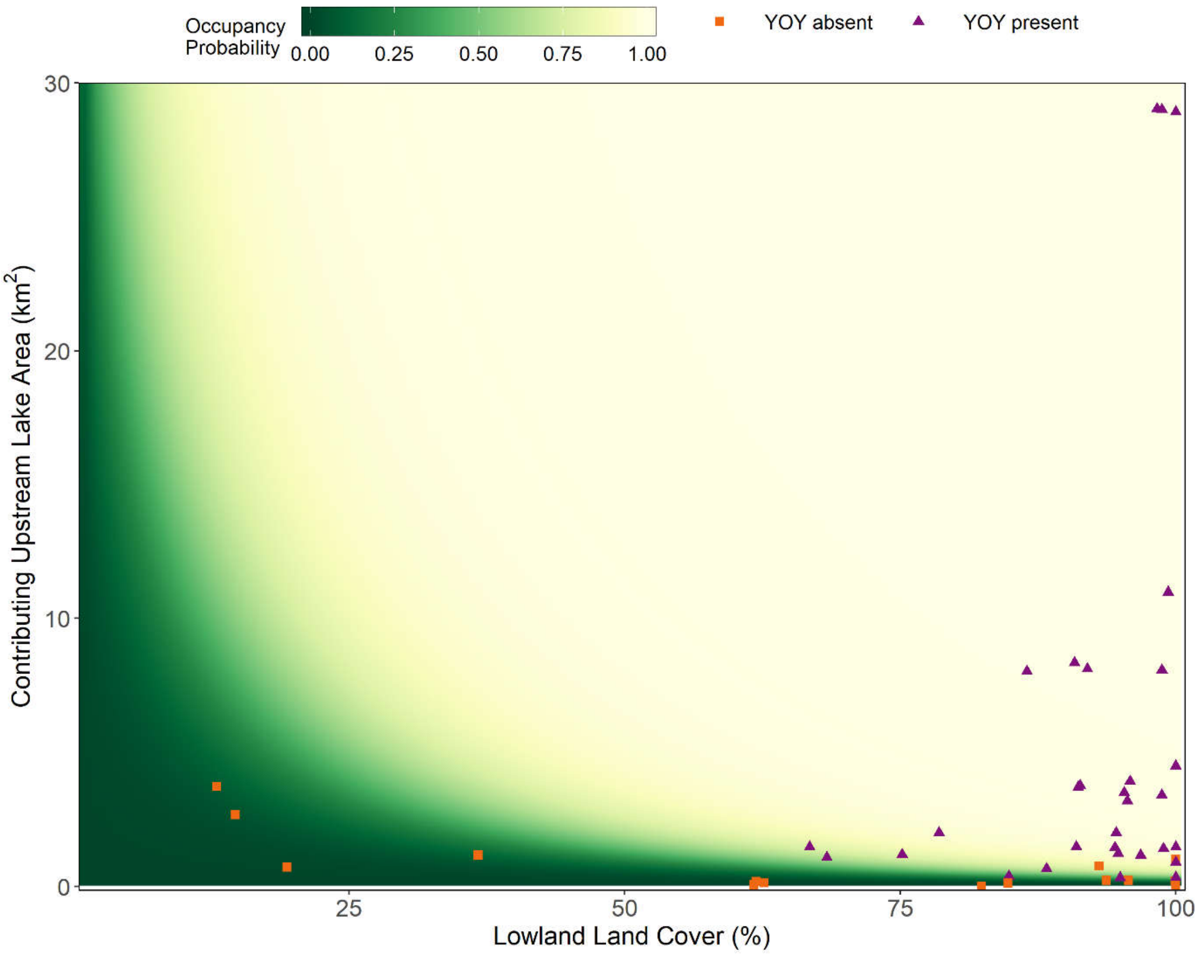


Figure 14. Bivariate plot of estimated occupancy of YOY as a function of percentage of lowland land cover and contributing upstream lake area. Orange squares represent the study streams where young-of-year were not detected, and purple triangles the study streams where young-of-year were detected. Combined, these two variables explain the occupancy results for 46 of the 48 streams included in the model.

Since a large portion of Figure 14 contains unsampled conditions, a bivariate plot with a reduced range of contributing upstream lake area is presented in Figure 15a; this allows for a more detailed examination of occupancy probability in the ranges of covariates where occupancy transitions between low and high. All sixteen unoccupied streams are shown in this figure. The absence of YOY Arctic Grayling in 10 of these 16 streams is clearly explained by insufficient contributing upstream lake area. An additional four unoccupied streams with relatively higher upstream lake areas had the lowest percentages of lowland land cover of any of the study streams. This suggests that upland streams 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 (Figure 15a).

To understand where uncertainty/certainty in occupancy probability is greatest, a plot of the range of 95% CI is shown in Figure 15b. The range is calculated as the upper limit of the 95% CI minus the lower limit of the 95% CI. The model predicts both presence and absence with confidence (i.e., small confidence interval range) under certain combinations of upstream lake area and land cover. There is high confidence that streams with low percentages of lowland land cover and small contributing upstream lake areas are unoccupied (Figure 15b). Similarly, there is high confidence that streams with high percentages of lowland land cover and large contributing upstream lake areas are occupied. Uncertainty is greatest where the two covariates have an opposing influence on occupancy. For instance, if a stream with a low percentage of lowland land cover also has a large contributing upstream lake area, there is increased uncertainty in the model result. This is particularly true for conditions that were under sampled, or less commonly found within the study area.

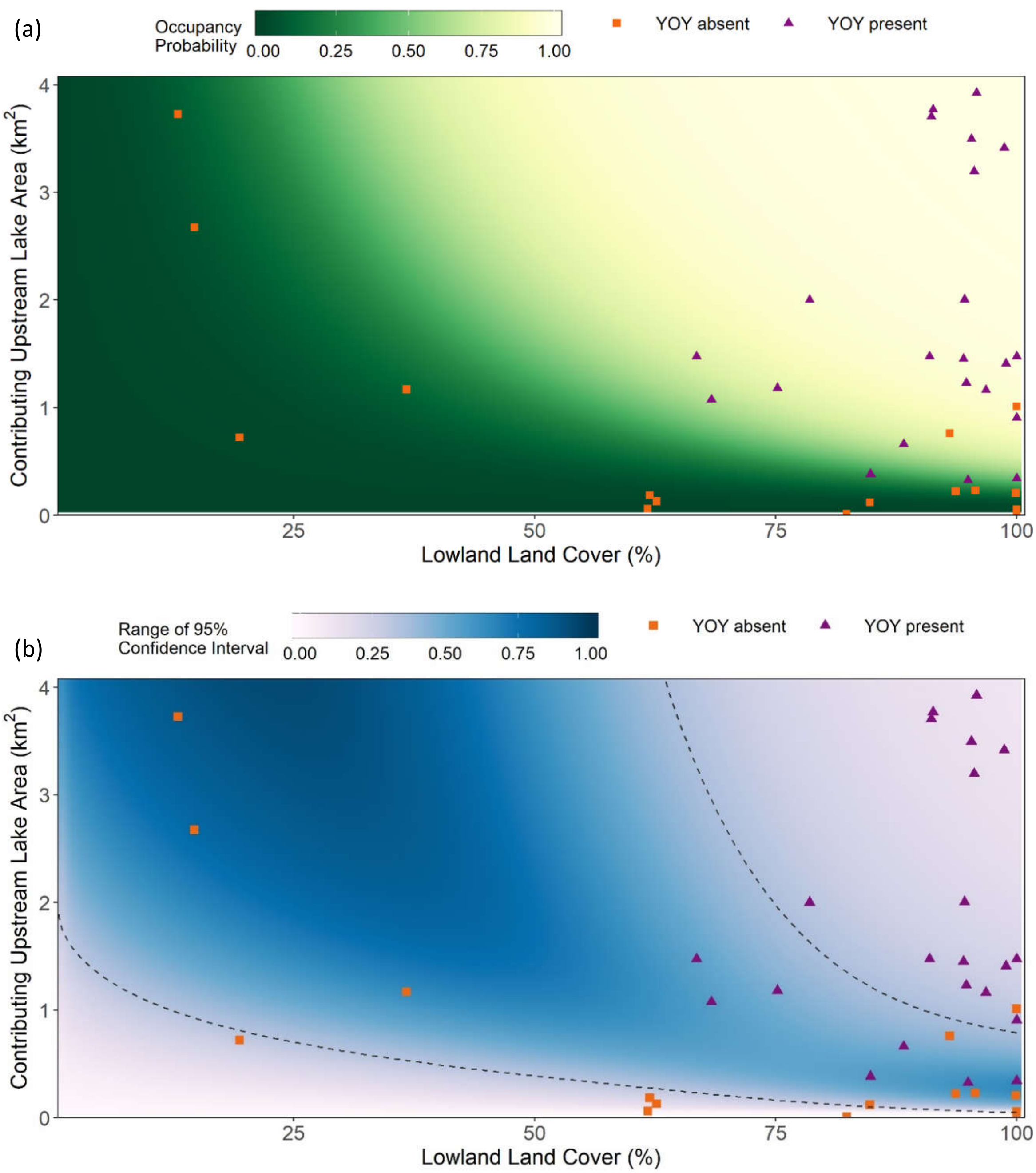


Figure 15. Bivariate plot of (a) estimated occupancy of YOY and (b) range of 95% confidence intervals for the occupancy estimate as a function of percentage of lowland land cover and contributing upstream lake area. Range of 95% confidence interval is calculated as the upper limit minus the lower limit. Orange squares indicate study streams where YOY were not detected, whereas purple triangles indicate study streams where YOY were detected. The dashed contour line identifies the 95% confidence interval range of 0.30, and shows that the model predicts both presence and absence with confidence (i.e., CI < 0.30), under certain combinations of upstream lake area and land cover.

3.6 Assessment of model fit

Model fit was evaluated using data previously collected from additional streams within the study area. Using the same method outlined in Section 2.2.3, land classification and contributing upstream lake area were calculated for 16 streams that were included in the test data set. Probability of occupancy was estimated using these covariate values, and streams were placed on an occupancy model biplot to assess how accurately the model predicted presence/absence of YOY Arctic Grayling (Figure 16a). The streams were also plotted on the biplot of the range of the 95% confidence interval (Figure 16b) to visualize uncertainty in predicted probability of occupancy. Of the sixteen independent streams assessed, four, which were sampled in the spring, were predicted by the model to contain YOY Arctic Grayling (Figure 16a). Arctic Grayling adults were detected in three of these four streams. No Arctic Grayling of any life stage were detected in the 12 remaining streams (Figure 16a). The absence of YOY in these streams was well-predicted by the model (Figure 16); probability of occupancy was <0.20 for 10 streams, whereas probability of occupancy was 0.48 and 0.66 in an additional two streams. The estimated occupancy probability of 0.66 for the one unoccupied stream was associated with a very large 95% CI (0.08-0.98).

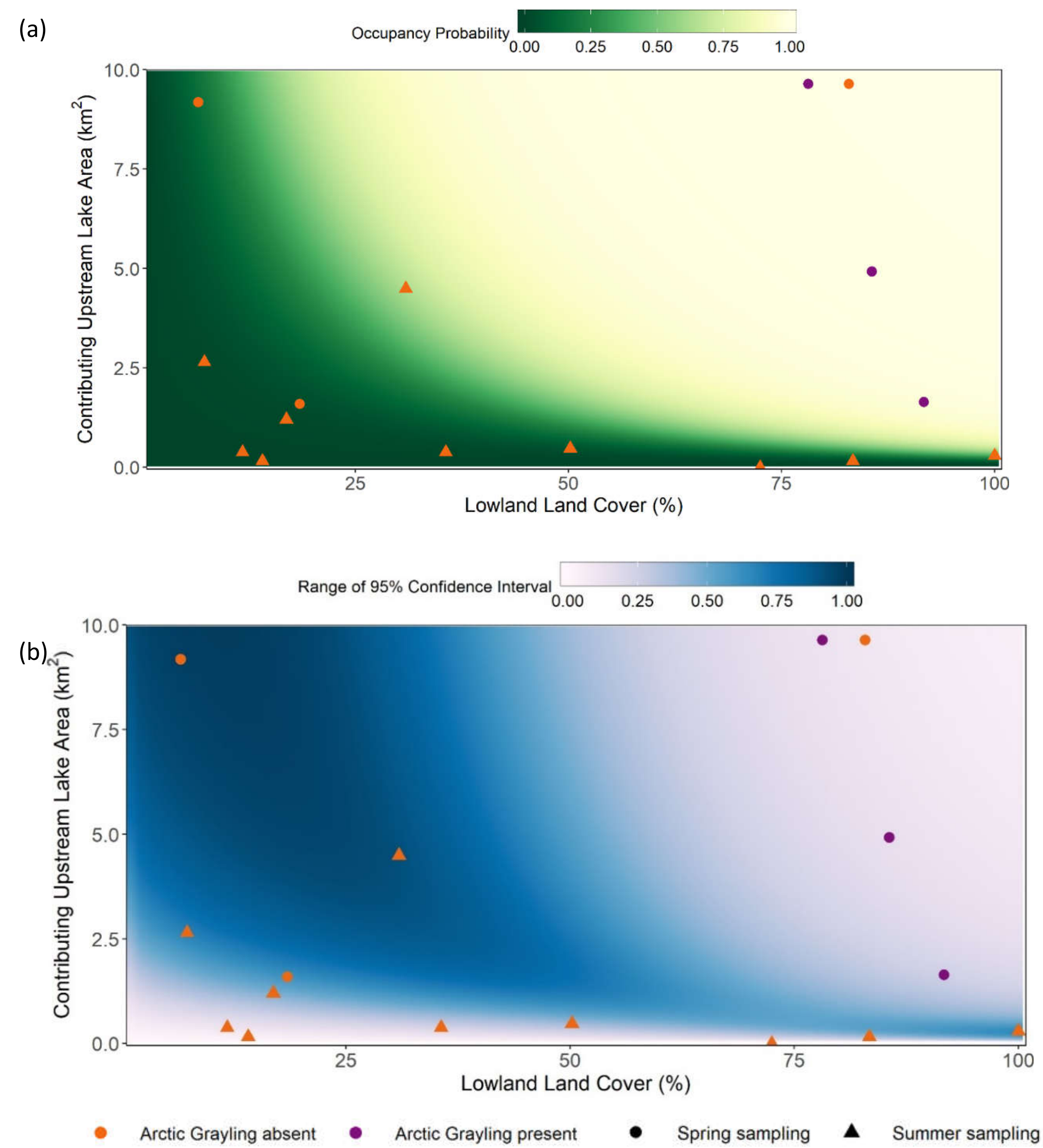


Figure 16. Bivariate plot of test stream (a) occupancy and (b) range of 95% confidence intervals for the occupancy estimate as a function of percentage of lowland land cover and contributing upstream lake area. Orange indicates streams where Arctic Grayling were not detected, while purple indicates streams where Arctic Grayling were detected. Circles represent spring sampling (adult spawning surveys), while triangles represent summer sampling. Three of the four streams surveyed during the spring detected adults where YOY are predicted based on the model. All twelve of the unoccupied streams had either low predicted occupancy probabilities (ten of twelve streams <0.2), or moderate probabilities with large uncertainties (e.g. 0.66 with a 95% CI of 0.08-0.98).

3.7 Comparison to other YOY studies

Results from this study (near Baker Lake) were compared to the findings from three other studies that assessed habitat use of YOY Arctic Grayling in various regions of the sub-Arctic. Two of the three studies (Jones and Tonn (2004) and Baker et al. (2017)) were conducted in the Barrenlands region of the NWT, and focused on within-stream habitat variables. As a result, comparisons of results between this study and the other two Barrenland studies were limited to two variables: depth and velocity. Depth and velocity were identified by both Jones and Tonn (2004) and Baker et al. (2017) as useful predictors of suitable habitat for YOY grayling, and although depth and velocity were not top predictors in this study, both are shown to have some predictive power, as occupancy models for depth and velocity have better AIC scores than the null model (see Appendix C for model results). In addition, depth and velocity are hydrological variables that likely respond to variability in upstream contributing lake area, as this study found that upstream contributing lake area and discharge were positively correlated (Appendix D; Figure D-1). A comparison of depth and velocity as they relate to habitat suitability for YOY grayling for all three studies is presented in Figure 17. Results from this study suggest that streams are increasingly likely to contain YOY grayling as average depth and average velocity increase. Whereas Baker et al. (2017) found the opposite relationship, the results from the larger YOY grayling that Jones and Tonn (2004) studied are somewhat consistent with results from this study over the ranges of depth and velocity that were found in both study systems; Jones and Tonn (2004) showed that as YOY mature (purple curves in Figure 17), they require deeper stream habitat with higher water velocities, and these results are most consistent with those generated for the Baker Lake study area.

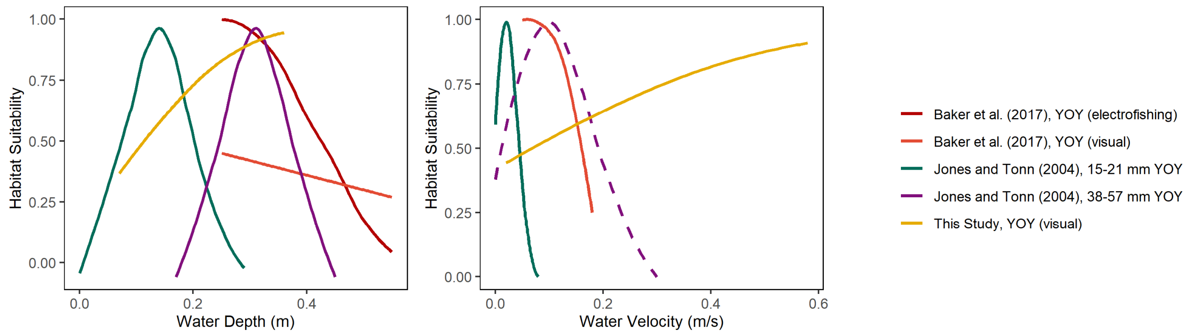


Figure 17. Suitability of depth and velocity conditions in Barrenland streams occupied by Arctic Grayling YOY, comparing findings from this study to results reproduced and synthesized from Jones and Tonn (2004) and Baker et al. (2017). Solid lines represent variables that contributed significantly to the models, whereas dashed lines represent variables that did not contribute significantly. Results from this study generally agree with results from Jones and Tonn (2004)

The authors of the Nahanni study assessed 35 randomly selected 'patches' within four sub-watersheds in the mountainous sub-Arctic region along the border of the NWT and Yukon (Lewis 2018). Of these, YOY were detected in only seven patches (naïve occupancy of 0.2). The best predictors of occupancy for these mountain streams were elevation (below 1150 masl) and water temperature (greater than 8°C). Comparing elevation results across all three occupancy studies (Figure 18a), it is evident that elevation does not influence habitat suitability for Barrenland populations of Arctic Grayling because the magnitude and variation in elevation among streams within the two Barrenland studies is low relative to the Nahanni study. Making a similar comparison of water temperature between studies (Figure 18b) shows that Barrenland streams were never below the 8°C temperature threshold that was observed for YOY presence/absence within the Nahanni streams. Additional comparisons of common habitat variables that were collected across occupancy projects, including depth, velocity, slope, and substrate, are presented in Appendix E.

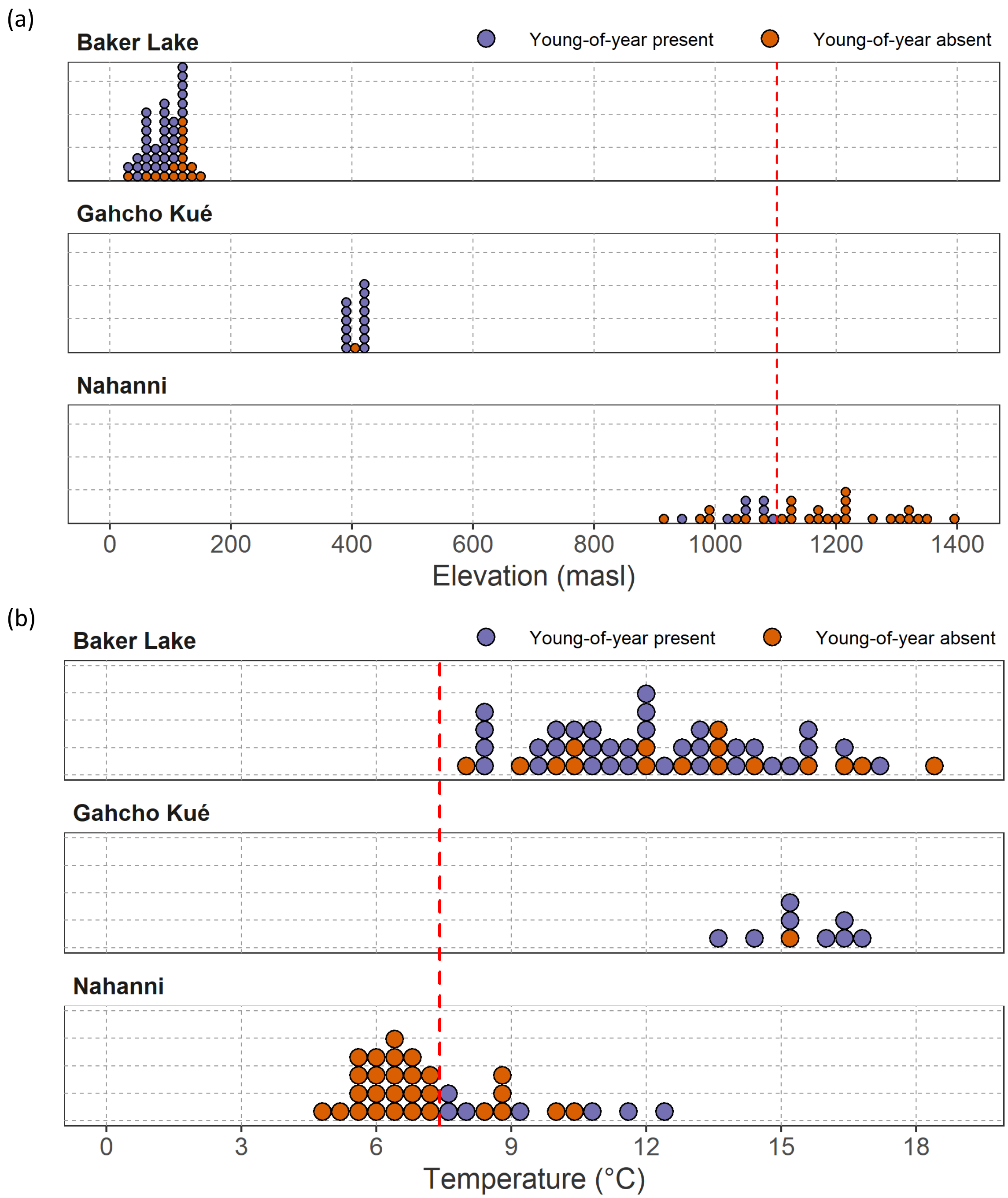


Figure 18. Distribution of (a) stream elevation and (b) water temperature for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream. Purple dots are occupied streams and orange dots are unoccupied streams. Dashed red lines indicate thresholds, beyond which streams were unoccupied. Elevation and temperature were found to be good predictors of occupancy in Nahanni, where streams above ~1150 masl and below ~8°C were unoccupied.

4.Discussion

4.1 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 Arctic Grayling YOY (Artym 2016) and Smallmouth Bass (*Micropterus dolomieu*) YOY (Brewer and 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 and Ellersieck (2011)) relative to velocities measured in this study (0.24 m/s).

In accordance with previous observations (e.g., Vascotto 1970; Jones and Tonn 2004), changes in YOY behaviour and microhabitat use over time were anecdotally observed within the study streams, and may have affected observed relationships between detection probability and water depth and velocity. Initially, in mid-July, when presence/absence surveys began, grayling YOY congregated in small schools in shallow, low velocity water along the margins of the stream. As YOY grew larger, habitat preference appeared to shift to deeper, higher velocity water (also observed by Jones and Tonn 2004). Therefore, stream depth and velocity likely had a reduced effect on detection probability earlier in the summer, when YOY inhabited the shallow, low velocity margins regardless of overall stream conditions. Later in the summer, as YOY sought deeper water with higher velocities, average conditions within the replicate would more accurately reflect the microhabitat use of YOY. Although using sample date as a detection covariate did not improve the model, the relationship between depth/velocity and date may become more apparent with a larger dataset that is collected over a longer period of the rearing season, and should be considered in future studies.

An assessment of fit of the detection probability model was completed using the bootstrapped χ^2 method developed by MacKenzie and Bailey (2004), and this analysis revealed that the model was overdispersed ($\hat{c}$ of 3.4). Unmodeled heterogeneity in detection probability was the suspected reason for this overdispersion, which means that there is a factor influencing the probability of detection that is not accounted for in the model. This could be a result of a missing covariate that affects detectability, but is more likely due to variation in abundance of YOY among streams. The size of the local population at each replicate impacts the probability of detection, and it has been suggested that this variation is at times the leading cause of heterogeneity in detection probabilities during occupancy studies (Royle and Nichols 2003). It is sometimes possible to account for variation in abundances using covariates (e.g., distance to overwintering habitat); however, as in this study, it is not always possible to identify and collect covariates that are well correlated with abundance (Royle and Nichols 2003). Collection of abundance estimates in place of presence/absence data would require a substantial increase in effort. An increase in effort would negate the benefits of using occupancy modeling by increasing costs and reducing the potential geographic scope, and accurate abundance estimates were not considered feasible for this study.

Abundance-induced heterogeneity in detection probability is more likely to be important for small populations, and less important as average population size increases and a constant detection probability becomes an acceptable approximation (MacKenzie et al. 2018). Based on the high fecundity of Arctic Grayling (3,243 to 15,905 eggs/female, Stewart et al. 2007), and an estimated fry production of 2.5% (Kruse 1959), it is expected that, given presence, the YOY population rearing within natal streams would be considerably higher than 10 individuals. However, observation rate (number of YOY detected per minute) across replicates suggests that abundance is not uniform among streams. While observation rate is not likely an accurate measure of abundance, the disparity between low and high observation rates (0.13 – 7.33 YOY/minute) suggests that it may be a reasonable approximation. Perfect detection occurred in streams with high observation rates (high abundance), and imperfect detection occurred in streams with low observation rates (low abundance). The higher than expected number of sites with low detection probabilities was the largest contributor to overdispersion in the model of detection probability. Considering this, it is likely that the source of variance is due to unmodelled variation in abundance among streams. It is difficult to quantify the impact of not accounting for variation in abundance among streams. Streams with low abundance of YOY could be misidentified as unoccupied and could potentially lead to misinterpretation of results. An increase in the number of replicates, or search time per replicate, may increase the likelihood of detecting a fish and reduce heterogeneity in detection probability. However, the value of spending more time at each site would need to be carefully considered relative to the cost of visiting a reduced number of sites, and the net benefit may vary by study, landscape, and focal species. An alternate option to model heterogeneity in abundance is to use observation rate to categorize streams based on relative abundance (e.g., unoccupied, occupied, highly occupied) for use in a multi-state occupancy model. However, an increased number of states requires also an increased sample size to produce reliable parameter estimates, and is likely not feasible in large landscape with challenging access, such as the Barrenlands.

4.2 Occupancy

The suitability of a Barrenland stream for YOY Arctic Grayling was strongly influenced by the landscape in which it was located. 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 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 Barrenland landscapes can be better understood.

Sixteen of 49 surveyed streams were unoccupied, and absence of Arctic Grayling YOY in 10 of the unoccupied streams could be explained by insufficient contributing upstream lake area. 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 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, this need for sustained flow cannot be overstated, as habitat connectivity is imperative for migration to overwintering lakes prior to freeze-up.

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 result indicated that upstream lakes contribute to maintaining baseflow in the Barrenland streams in the study area, and that unoccupied streams with low contributing upstream lake area were likely unsuitable for YOY Arctic Grayling due to insufficient discharge. The data collected for this study suggest that contributing upstream lake area may in fact be used as a reliable surrogate for discharge in Barrenland landscapes, and allow for comparisons among streams when discharge measurements cannot be taken on the same day or within a short temporal window. Stream discharge measurements were collected across the 23-day survey period, during which time a range of environmental conditions, including periods of dry weather followed by heavy rain events (including one event where 48 mm of rain fell in less than 72 hours), influenced discharge and confounded comparisons among streams (see Figure D-1 in Appendix D). Incorporating contributing upstream lake area into the model in place of discharge allowed for a comparison among streams that was more representative of longer-term conditions.

Streams with small contributing upstream lake area and low discharge had other habitat features that were likely unsuitable for Arctic Grayling YOY. Many of these small streams were dominated by organic substrates and instream vegetation, likely because there was insufficient flow to mobilize even fine substrates. In fact, the six streams with highest % organic substrate were part of the group of ten streams where non-occupancy was explained by low contributing upstream lake area. Arctic Grayling are known to prefer inorganic substrate for spawning, particularly gravel (Stewart et al. 2007), and high relative % organic material within streams that have small upstream lake area and low discharge may render the habitat unsuitable for spawning adults, leading to absence of YOY. Organic substrate was also highly correlated with stream temperature metrics; streams dominated by organic substrate had less stable temperature profiles, with daily temperature fluctuations of up to 8°C and maximum temperatures that sometimes exceeded 20°C. While thermal tolerance of Arctic Grayling YOY have been found to exceed 24°C (LaPerriere and Carlson 1973), these large, daily fluctuations in water temperature may have affected occupancy, but further research is required.

Whereas insufficient contributing upstream lake area explained absence of YOY in 10 of 16 unoccupied streams, Arctic Grayling YOY were absent in six streams even through there was likely sufficient streamflow. The absence of YOY in four of these remaining streams was explained by land classification. The majority of streams included in this study were situated within lowland-dominated landscapes; however, four study streams where YOY were absent had relative upland land cover that exceeded 50%. Since Barrenland streams are colluvial, upland streams are dominated by unconfined boulder channels with large interstitial spaces (see Figure A-2 in Appendix A, for example). While literature on barriers to Arctic Grayling migration in the Barrenlands is lacking, these boulder-dominated streams with poorly defined channels lead to subsurface flow, and are known to influence migration of salmonids in other regions of the Arctic, including Arctic Char (*Salvelinus alpinus*) in Ungava Bay, Quebec (Power and Barton 1987). The reduction in flow that is observed across Barrenland streams as the summer progresses is increasingly likely to result in losses of surface connectivity in upland landscapes, as interstitial spaces coupled with unconfined channel structures promote subsurface flow at low discharges rather than overland flow. Indeed, this was observed at several upland study streams in late summer (Figure A-2b), and suggests that a larger contributing upstream lake area is required to maintain connectivity throughout summer for streams dominated by the upland land class.

For two of the 16 unoccupied streams, the absence of Arctic Grayling YOY was not explained by contributing upstream lake area and land classification. One of these streams appeared to have excellent fish habitat, and during presence/absence surveys for YOY, one adult Arctic Grayling and at least six juvenile salmonids of unknown species were observed. Juvenile and/or adult salmonids were observed during surveys in 19 of the 33 occupied streams, suggesting that predation pressure is not unique to this stream and YOY absence is unlikely to be explained by predation. Connectivity along this stream was high, and stream habitat variables were well within the range typically observed for occupied sites. It is possible that YOY were indeed present in the study stream, but remained undetected in all five replicate surveys, although the high occupancy and detection probabilities for this stream make this unlikely. The absence of YOY in this stream can thus not be explained by variables measured in this study.

In the second stream where absence of YOY was not explained by the model that included upstream contributing lake area and land classification, no fish of any type were detected during presence/absence surveys. Upon returning to the stream on August 31st, it was observed that stream connectivity was poor and a segment of the stream flowed exclusively through the subsurface, under a large boulder field covered with dense shrubs. This area had ecological land classifications of shrub and shrub/heath tundra, which are classifications that fall just outside the upland land class. This finding highlights a possible limitation of using land classification as a predictor for occupancy: classifications were developed as a tool for wildlife biologists to identify habitat over a large spatial scale, and were not intended for detailed, local mapping (Campbell et al.

2012). With a pixel size of 25 m x 25 m, small changes in local habitat are easily missed, which can lead to misclassified data at small, stream-level scales.

As with any model, it is important to validate predictions with independent data (Houlahan et al. 2017). The predictive power of the model developed in this study was evaluated through use of an independent test dataset that included 16 streams. For the three streams where adults were detected, the model predicted with high confidence that these streams were occupied. Although only adults were detected, all three streams were sampled in spring (late June), with the objective of identifying suitable spawning habitat (C. Portt and Associates 2018). The presence of adults in streams in late June is an indicator of suitable spawning habitat and, given the strong site fidelity of Arctic Grayling during spawning and summer feeding (Northcote 1995; Deegan et al. 1999; Buzby and Deegan 2000), it is also an indicator of suitable rearing conditions for YOY. A fourth stream sampled during spring spawning surveys did not appear to contain Arctic Grayling adults, even though the model predicted a high probability of occupancy for YOY. However, a potential migration barrier exists between this stream and the presumed overwintering location for the population, as a long, steep set of rapids is present within the migratory pathway (C. Portt and Associates 2018). Barriers such as these were not observed within the study streams and therefore were not incorporated in the model, thereby presenting a potential limitation to prediction.

Many of the remaining test streams that did not contain YOY were predicted by the model to have a very low probability of occupancy (10 of 12 streams had a probability of <0.20), as most had insufficient contributions from upstream lakes or high percentages of upland land cover. The remaining two streams had higher occupancy probabilities (0.48 and 0.66), but these estimates were associated with large 95% confidence intervals (0.18-0.81 and 0.08-0.98, respectively). Overall the model performed well to predict unoccupied test streams. Further validation using streams sampled in the summer, where the model predicts with high likelihood that YOY are present would be of benefit, as these conditions were not common within the test dataset.

4.3 Comparison to other YOY studies

A comparison of results from this study to other Arctic Grayling YOY habitat studies completed in the Barrenlands illustrated some of the challenges of synthesizing results from studies completed to date, but also highlight some broad-scale patterns in occupancy of YOY grayling in northern landscapes. Challenges in comparing and synthesizing results included among-study differences in experimental design, as each study was developed to address site-specific objectives, and differences in methods. For instance, hydrological (or in this study, hydrological proxy) variables emerge from all three studies) as in predicting occupancy of YOY grayling. Sampling methodology for depth and velocity differed among the three Barrenlands studies, however; Jones and Tonn (2004) measured depth and velocity at locations where individual fish were observed, Baker et al. (2017) took measurements along the thalweg of the stream (parallel to flow), and this study averaged depth and velocity along a transect perpendicular to stream flow. Jones and Tonn (2004) found that YOY grayling used different habitats as the rearing season progressed. As YOY grayling grew, they transitioned from shallow, low velocity water along the stream margins to deeper, higher velocity water. In this study, streams were more likely to contain YOY grayling as average depth and average velocity increased. Streams with higher depth and velocity would provide the habitat found by Jones and Tonn (2004) to be more suitable for later-season YOY grayling, but, consistent with Baker et al. (2017), would also likely contain suitable habitat for early-season YOY individuals (i.e., shallow, low flow) along stream margins. That is, results from this study cannot be concluded to be inconsistent with those reported by Baker et al. (2017), because of differences in where and how measurements were taken.

Comparing occupancy results from studies completed in different regions of the Arctic/sub-Arctic suggests that the factors that limit the suitability of stream habitat for YOY grayling differ based on the landscape in which the streams are located. Occupancy of YOY grayling in sub-Arctic mountain streams are limited by high elevations (~1150 masl) and cold water temperatures (~ 8°C). However, in other Arctic landscapes, such as the Barrenlands, where variation in elevation is negligible and water temperatures during the rearing period are consistently greater than 8°C, these habitat variables do not limit the suitability of streams for YOY grayling. Instead, other variables, such as those related to connectivity, better predictors of occupancy. Furthering our understanding of which habitat characteristics are critical for YOY grayling across various Arctic landscapes will lead to improved conservation and mitigation policies.

5. Implications and Conclusions

5.1 Development

This research indicates that within the Barrenlands, the suitability of stream habitat for YOY Arctic Grayling is limited by connectivity. Connectivity of the lake-stream networks throughout the open water season is essential for migrating YOY, who must leave rearing streams prior to freeze-up to reach overwintering habitat in lakes. 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; Jones and Stanley 2016). 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. This suggests that alterations in lake-stream connectivity in the headwaters of a watershed may have considerable impact on the hydrologic conditions downstream, and consequently the suitability of streams for YOY rearing. Assessing how alterations in flow may influence downstream conditions and hydrological connectivity should thus be a critical priority when investigating potential effects of development projects (e.g., road construction and resource extraction) in Barrenland landscapes. It will be important to quantify the potential losses of contributing upstream lake area and to assess if, given these losses, how habitat suitability in downstream systems may be impacted. The model developed in this study allows practitioners to predict changes in YOY grayling occupancy probability downstream of proposed resource development projects, considering any connectivity modifications that are proposed. The potential impacts of such developments were highlighted at Gahcho Kué, where the construction of a cofferdam and draining of a relatively large lake led to habitat fragmentation, an eventual reduction in downstream flow, and the collapse of the Arctic Grayling population (Baker et al., in prep.).

When assessing potential impacts to stream habitat as a result of development projects, it is worth considering the relative importance of an occupied stream for the population. Overall, the availability of suitable stream habitat changes across the landscape, and reduced availability of suitable habitat increases the relative importance of a single occupied stream. For instance, during the baseline studies for construction of the 110 km all-weather access road from Baker Lake to

Meadowbank, a total of 6 of 25 streams were found to support Arctic Grayling migration, spawning, and/or rearing (Cumberland Resources Ltd. 2005; Azimuth Consulting Group 2008). Comparatively, during the baseline study for the ~65 km extension of the road from Meadowbank to Amaruq, only one of eleven streams was found to support Arctic Grayling (C. Portt and Associates 2015). This lower proportion of suitable streams is correlated with a change in landscape. Between Baker Lake and Meadowbank, lowland land cover dominates the landscape, whereas upland land cover becomes increasingly common between Meadowbank and Amaruq (see Figure E-6 in Appendix F). In lowland regions, stream connectivity within chain-lake systems is strong, as 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 for YOY rearing within this landscape. This reduction in available stream habitat places increased importance on the few streams within upland regions where YOY Arctic Grayling are present. As a result, the impact of development on a single stream in an upland-dominated landscape may be of greater consequence, and therefore the landscape in which the project is proposed should be considered during environmental assessments.

Possibly the most interesting and potentially valuable outcome of this study is that YOY Arctic Grayling stream occupancy is best predicted using variables that can be remotely sensed. Of all the habitat variables assessed, the majority of which can only be collected while onsite, the best predictors of stream occupancy were found to be contributing upstream lake area and land classification. Both these variables can be calculated in GIS, using publicly available shapefiles (Campbell et al. 2012; Natural Resources Canada 2016b). This finding is expected to result in considerable cost savings during future development, as it is incredibly expensive to conduct remote Arctic fieldwork in support of environmental baseline monitoring. The occupancy model developed here can be used during preliminary assessments to determine the probability that a stream supports Arctic Grayling. Having this information early in the life of a project allows for modifications in the proposed design to be made without undue financial consequence.

5.2 Future Research

This research has led to the identification of two landscape variables that can be used to predict the probability that a Barrenland stream is used by Arctic Grayling YOY. These variables (contributing upstream lake area and land class) can be assessed remotely, and therefore streams with specific conditions can be targeted and selected for occupancy surveys. By incorporating streams with conditions that are under-represented in the current model (e.g., moderate contributions of upstream lake area with moderate to low percentages of lowland land class), the large uncertainties (range of the 95% CI) that are currently observed could be reduced. Additional sampling even within the ranges of variables already surveyed would also reduce overall uncertainty around occupancy estimates and improve confidence in the results. Future development of nearby mineral deposits is likely as exploration in the barrenlands region continues. Considering this, there is great potential to implement and expand on the predictive tool developed here. By increasing the geographic scope, a more holistic model can be developed, incorporating different landscapes that may not be present within the current study area.

The ecological land classification data used in this analysis were simplified from twelve different vegetation communities to two landscape classes (i.e., upland vs. lowland). This suggests that a full ecological land classification dataset, which is expensive to produce and therefore has not been completed across most of the Arctic, is not required. It may be worthwhile to investigate the utility of using satellite imagery to distinguish between upland vs. lowland land cover. This could be done in GIS using supervised classification, selecting known areas of each land cover class as a training data set, and classifying the remainder of the image. Landsat imagery at 30 m resolution is freely available online (Natural Resources Canada 2018b), and while it has been suggested that a coarse resolution may cause small changes in local habitat to be missed (see Section 4.1), the multi-spectral band combinations available with Landsat imagery are advantageous for distinguishing between the spectral signatures of different types of ground cover (Campbell et al. 2012).

5.3 Final Remarks

The Barrenlands are dominated by networks of lakes and streams that are seasonally connected, and support an adfulvial life history for populations of Arctic Grayling. Barrenland populations of

Arctic Grayling rely on networks of lakes and streams to migrate, spawn, and rear, and the results from this study emphasize the importance of connectivity throughout the ice-off period, particularly for YOY rearing in streams during the summer and migrating to overwintering lakes prior to freeze-up. Stream position in the landscape defines the reliability of stream connectivity, and thus suitability for YOY. Findings of this study suggest that this suitability can be predicted remotely, using two landscape variables: contributing upstream lake area and land classification. The occupancy model developed here can be used as a valuable predictive tool for Arctic Grayling YOY stream use in the Barrenlands, and can better inform regulators, scientists and industry, facilitating the development of more effective conservation and mitigation plans.

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Appendix A: Upland and lowland stream examples

Figure A-1. Representative photographs of streams situated in a (a) lowland dominated landscape and (b) upland dominated landscape. Lowland landscapes are defined by poorly drained substrates dominated by organics, whereas the upland landscapes are defined by well-drained inorganic substrates, such as gravel, boulder, and bedrock.

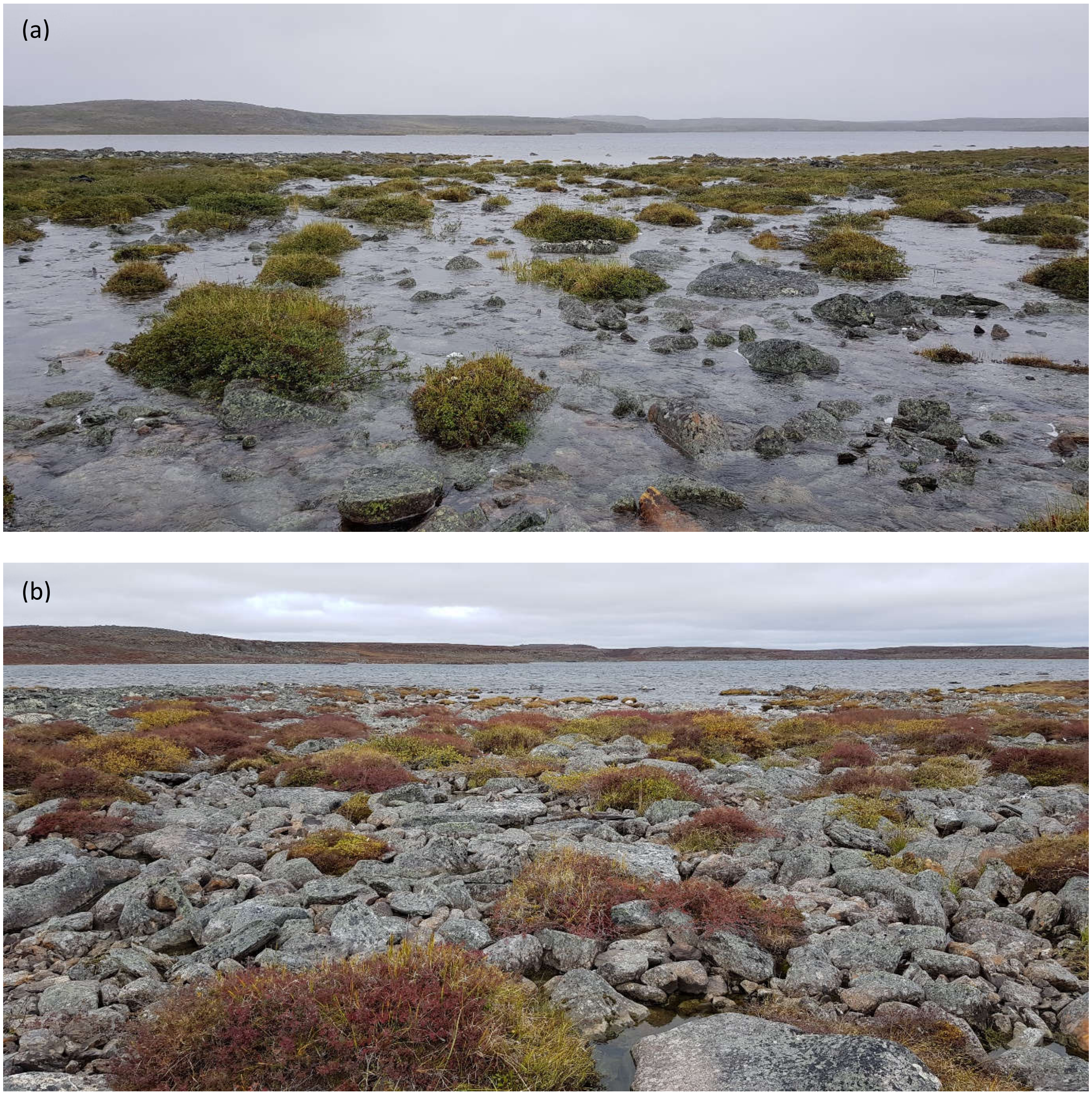

Figure A-2. Unoccupied study stream dominated by upland land cover (80%) on (a) August 08, 2019 following a significant rainfall event, and (b) September 03, 2019. The reduction in flow between the two dates resulted in a loss of surface connectivity, as most flow is subsurface, through interstitial spaces between boulders.

Appendix B: Correlation Data

Table B-1. Pairwise comparisons of correlation (Pearson's r) between occupancy covariates.

	DO	DO Saturation	Specific Conductivity	pH	Discharge	Mean Depth	Mean Velocity	Instream Vegetation	Wetted Width	# of Channels	Slope	Overhanging Vegetation	Undercut Banks
DO													
DO Saturation	0.56												
Specific Conductivity	0.21	0.41											
pH	0.19	0.39	0.55										
Discharge	0.07	0.10	-0.08	0.09									
Mean Depth	-0.08	-0.06	-0.04	0.04	0.49								
Mean Velocity	-0.07	-0.11	-0.20	-0.10	0.39	0.38							
Instream Vegetation	-0.07	-0.03	-0.01	-0.28	-0.14	-0.17	0.01						
Wetted Width	0.16	0.08	-0.19	0.16	0.61	0.32	-0.02	-0.30					
# of Channels	-0.26	-0.17	-0.16	-0.13	-0.14	-0.11	0.25	-0.04	-0.17				
Slope	-0.09	-0.28	-0.23	-0.15	-0.15	-0.39	0.33	0.17	-0.25	0.34			
Overhanging Vegetation	0.00	-0.07	-0.08	-0.06	-0.06	0.00	0.17	-0.04	-0.07	0.30	0.26		
Undercut Banks	0.04	0.01	0.04	0.07	-0.06	0.32	0.03	-0.09	-0.15	-0.10	-0.18	0.13	
Bedrock	0.11	-0.02	0.04	0.10	-0.07	-0.19	0.00	-0.12	-0.05	-0.02	0.28	0.11	-0.05
Boulder	0.08	-0.09	-0.12	0.19	0.10	0.10	0.14	-0.54	0.38	0.15	0.14	0.14	-0.24
Cobble	0.12	0.08	0.21	0.26	0.23	0.18	0.09	-0.31	0.02	-0.16	-0.27	-0.13	0.29
Gravel	0.09	0.07	0.20	0.25	0.06	0.13	-0.03	-0.13	-0.03	-0.18	-0.23	0.04	0.36
Sand	0.09	0.17	0.00	-0.18	-0.14	0.09	-0.12	0.18	-0.26	0.07	-0.21	0.08	0.12
Fines	0.06	-0.05	-0.19	-0.14	-0.06	-0.14	-0.16	-0.01	0.04	-0.10	-0.15	-0.09	-0.05
Organics	-0.19	0.01	-0.05	-0.40	-0.22	-0.23	-0.17	0.74	-0.37	-0.02	0.09	-0.11	-0.04
Mean Temperature Range	-0.13	0.07	0.29	-0.20	-0.45	-0.41	-0.34	0.63	-0.50	-0.10	0.08	0.06	0.04
Mean Daily Temperature CV	-0.12	0.02	0.24	-0.23	-0.44	-0.42	-0.35	0.61	-0.45	-0.09	0.10	0.06	0.05
ATU	-0.04	0.28	0.31	0.24	-0.13	0.16	0.01	0.16	-0.32	-0.03	-0.22	0.05	-0.03
Mean Daily Max Temp.	-0.16	0.21	0.42	-0.02	-0.36	-0.22	-0.28	0.60	-0.50	-0.12	-0.09	0.05	0.04
Mean Daily Min Temp.	0.07	0.13	-0.04	0.30	0.27	0.43	0.29	-0.39	0.19	0.06	-0.20	-0.02	-0.05
Upstream Lake Area	0.19	0.26	-0.06	0.21	0.87	0.42	0.34	-0.24	0.64	-0.19	-0.22	-0.10	-0.05
Land Classification	0.15	0.19	0.14	0.08	0.13	0.04	0.19	0.25	-0.09	0.07	-0.07	0.13	0.12

Table B-1. (continued)

	Bedrock	Boulder	Cobble	Gravel	Sand	Fines	Organics	Mean Temperature Range	Mean Daily Temperature CV	ATU	Mean Daily Max Temp.	Mean Daily Min Temp.	Upstream Lake Area	Land Classification
DO														
DO Saturation														
Specific Conductivity														
pH														
Discharge														
Mean Depth														
Mean Velocity														
Instream Vegetation														
Wetted Width														
# of Channels														
Slope														
Overhanging Vegetation														
Undercut Banks														
Bedrock														
Boulder	0.03													
Cobble	0.00	-0.27												
Gravel	0.13	-0.50	0.71											
Sand	-0.11	-0.49	0.06	0.29										
Fines	-0.04	-0.03	0.18	0.14	0.09									
Organics	-0.12	-0.67	-0.48	-0.24	0.27	-0.12								
Mean Temperature Range	-0.03	-0.56	-0.27	-0.13	0.19	-0.05	0.74							
Mean Daily Temperature CV	-0.01	-0.53	-0.26	-0.13	0.17	0.01	0.71	0.99						
ATU	-0.17	-0.14	0.03	0.04	0.18	-0.40	0.11	0.09	-0.06					
Mean Daily Max Temp.	-0.14	-0.56	-0.17	-0.03	0.27	-0.21	0.65	0.86	0.78	0.54				
Mean Daily Min Temp.	-0.09	0.35	0.21	0.12	-0.04	-0.22	-0.50	-0.74	-0.83	0.60	-0.32			
Upstream Lake Area	0.00	0.11	0.27	0.14	-0.14	-0.04	-0.28	-0.47	-0.45	-0.18	-0.41	0.25		
Land Classification	-0.08	-0.33	0.23	0.25	0.13	-0.04	0.13	0.18	0.16	0.17	0.23	-0.04	0.20	

Table B-2. Pairwise comparisons of correlation (Pearson's r) between detection covariates.

	Cloud Cover	Rain	Instream Vegetation	Slope	Overhanging Vegetation	Undercut Banks	Bedrock	Boulder	Cobble	Gravel	Sand	Fines	Organics	Average Depth	Average Velocity	Day	Time of Day
Cloud Cover																	
Rain	0.40																
Instream Vegetation	0.06	-0.05															
Slope	0.10	-0.03	0.11														
Overhanging Vegetation	0.12	-0.04	-0.05	0.25													
Undercut Banks	0.08	-0.07	-0.09	-0.10	0.15												
Bedrock	0.11	-0.02	-0.06	0.27	0.08	-0.02											
Boulder	-0.08	0.12	-0.48	0.15	0.14	-0.19	0.03										
Cobble	0.01	-0.08	-0.30	-0.24	-0.12	0.25	-0.07	-0.29									
Gravel	0.13	-0.10	-0.12	-0.25	0.01	0.28	-0.03	-0.50	0.61								
Sand	0.07	-0.03	0.12	-0.12	0.04	0.08	-0.04	-0.37	-0.02	0.23							
Fines	0.09	0.24	0.02	-0.08	-0.03	-0.02	-0.01	-0.05	0.08	0.06	0.17						
Organics	0.00	-0.04	0.70	0.07	-0.11	-0.05	-0.06	-0.64	-0.46	-0.24	0.16	-0.05					
Average Depth	-0.06	-0.10	-0.13	-0.29	0.01	0.19	-0.06	0.06	0.11	0.12	0.14	-0.06	-0.18				
Average Velocity	-0.10	-0.16	-0.05	0.30	0.13	0.05	0.03	0.12	0.10	-0.03	-0.11	-0.08	-0.15	0.16			
Day	0.19	0.24	0.24	0.18	-0.08	-0.19	-0.11	0.11	-0.48	-0.47	0.12	0.06	0.32	-0.16	-0.01		
Time of Day	-0.17	-0.06	0.14	-0.10	-0.04	-0.13	-0.14	-0.08	-0.12	-0.10	0.01	0.00	0.19	-0.04	0.03	-0.08	

Appendix C: Occupancy Model Summary Table

Table C-1. Summary of candidate models and β coefficients with associated standard error for Arctic Grayling young-of-year occupancy in Barrenland streams. Models containing pretending variables are highlighted in grey. Coefficients for pretending variables (standard error of the β coefficient overlaps 0) are identified in red.

Model[1]	AICc	-2l	ΔAICc	Weight	Coefficients Estimate (±SE)				
					Intercept	$\sqrt{Lowland\,\%}$	log(Upstream Lake Area)	$\sqrt{Inorganic\,\%}$	Slope
$\psi\left(\sqrt{Lowland\,\%}+\log(Upstream\ Lake\ Area)\right)$	175.54	158.74	0.00	0.63	2.02 (0.82)	1.97 (0.74)	4.10 (1.44)	-	-
$\psi\left(\sqrt{Lowland\,\%}+\log(Upstream\ Lake\ Area)+\sqrt{Inorganic\,\%}\right)$	178.20	158.51	2.66	0.17	1.88 (0.86)	1.97 (0.74)	3.72 (1.58)	0.44 (0.99)	-
$\psi\left(\sqrt{Lowland\,\%}+\log(Upstream\ Lake\ Area)+Slope\right)$	178.42	158.72	2.88	0.15	2.02 (0.82)	1.96 (0.75)	4.05 (1.49)	-	-0.08 (0.60)
$\psi\left(\sqrt{Lowland\,\%}+\log(Upstream\ Lake\ Area)+\sqrt{Inorganic\,\%}+Slope\right)$	180.97	158.23	5.43	0.04	1.78 (0.87)	1.92 (0.72)	3.20 (1.72)	0.82 (1.29)	-0.41 (0.78)
$\psi\left(\sqrt{Lowland\,\%}+\sqrt{Inorganic\,\%}+Slope\right)$	184.09	164.40	8.56	0.01	0.69 (0.56)	2.14 (0.98)	-	2.99 (1.38)	-1.29 (0.61)
$\psi\left(\sqrt{Lowland\,\%}+\sqrt{Inorganic\,\%}\right)$	187.02	170.22	11.48	0.00	0.53 (0.50)	2.17 (0.88)	-	2.38 (1.08)	-
$\psi\left(\log(Upstream\ Lake\ Area)\right)$	189.62	175.58	14.09	0.00	1.09 (0.44)	-	2.35 (0.70)	-	-
$\psi\left(\log(Upstream\ Lake\ Area)+Slope\right)$	191.96	175.16	16.42	0.00	1.09 (0.44)	-	2.24 (0.71)	-	-0.27 (0.41)
$\psi\left(\log(Upstream\ Lake\ Area)+\sqrt{Inorganic\,\%}\right)$	192.37	175.57	16.83	0.00	1.07 (0.47)	-	2.30 (0.82)	0.06 (0.68)	-
$\psi\left(\sqrt{Inorganic\,\%}+Slope\right)$	199.10	182.30	23.57	0.00	0.68 (0.40)	-	-	1.67 (0.72)	-0.91 (0.40)
$\psi\left(\sqrt{Lowland\,\%}+Slope\right)$	199.72	182.92	24.18	0.00	0.71 (0.40)	1.55 (0.72)	-	-	-0.84 (0.39)
$\psi\left(\sqrt{Inorganic\,\%}\right)$	202.17	188.13	26.64	0.00	0.63(0.37)	-	-	1.45 (0.64)	
$\psi\left(\sqrt{Lowland\,\%}\right)$	202.22	188.17	26.68	0.00	0.62(0.37)	1.51 (0.66)	-	-	-
$\psi\,(Slope)$	208.82	194.78	33.29	0.00	0.75 (0.33)	-	-	-	-0.72 (0.33)
$\psi\,(\cdot)$	211.41	199.98	35.87	0.00	0.69 (0.31)	-	-	-	-
$\psi\,(\cdot)\ p(\cdot)$	219.78	215.52	44.24	0.00	0.69 (0.31)	-	-	-	-

[1] Probabilty of detection held constant at $p(Depth \times Gravel)$, with the exception of the null model

Table C-2. Summary of depth and velocity models and β coefficients with associated standard error for Arctic Grayling young-of-year occupancy in Barrenland streams. Models were constructed to facilitate a comparison of depth and velocity habitat suitability among Barrenland studies. Models containing pretending variables are highlighted in grey. Coefficients for pretending variables (standard error of the β coefficient overlaps 0) are identified in red.

Model	AICc	ΔAICc	-2l	Weight	Evidence Ratio	Coefficient Estimates (±SE)			
						Intercept	Depth	Velocity	Depth*Velocity
$\psi\,(Depth)$	208.38	0.00	194.33	0.45	1.00	0.82 (0.34)	0.86 (0.41)	-	-
$\psi\,(Depth + Velocity)$	210.19	1.81	193.39	0.18	2.47	0.85 (0.35)	0.58 (0.36)	0.37 (0.40)	-
$\psi\,(Depth \times Velocity)$	210.68	2.30	190.99	0.14	3.16	0.90 (0.41)	1.09 (0.58)	0.50 (0.44)	0.75 (0.54)
$\psi\,(Velocity)$	211.11	2.73	197.06	0.12	3.91	0.75 (0.32)	-	0.58 (0.36)	-
$\psi\,(\cdot)$	211.41	3.02	199.98	0.10	4.53	0.69 (0.31)	-	-	-
$\psi\,(\cdot)\,p\,(\cdot)$	219.78	11.40	215.52	0.00	302.93	0.69 (0.31)	-	-	-

[1] Probabilty of detection modelled as $p(Depth \times Velocity)$, with the exception of the null model, $\psi\,(\cdot)\,p\,(\cdot)$

Appendix D: Correlation of contributing upstream lake area and discharge

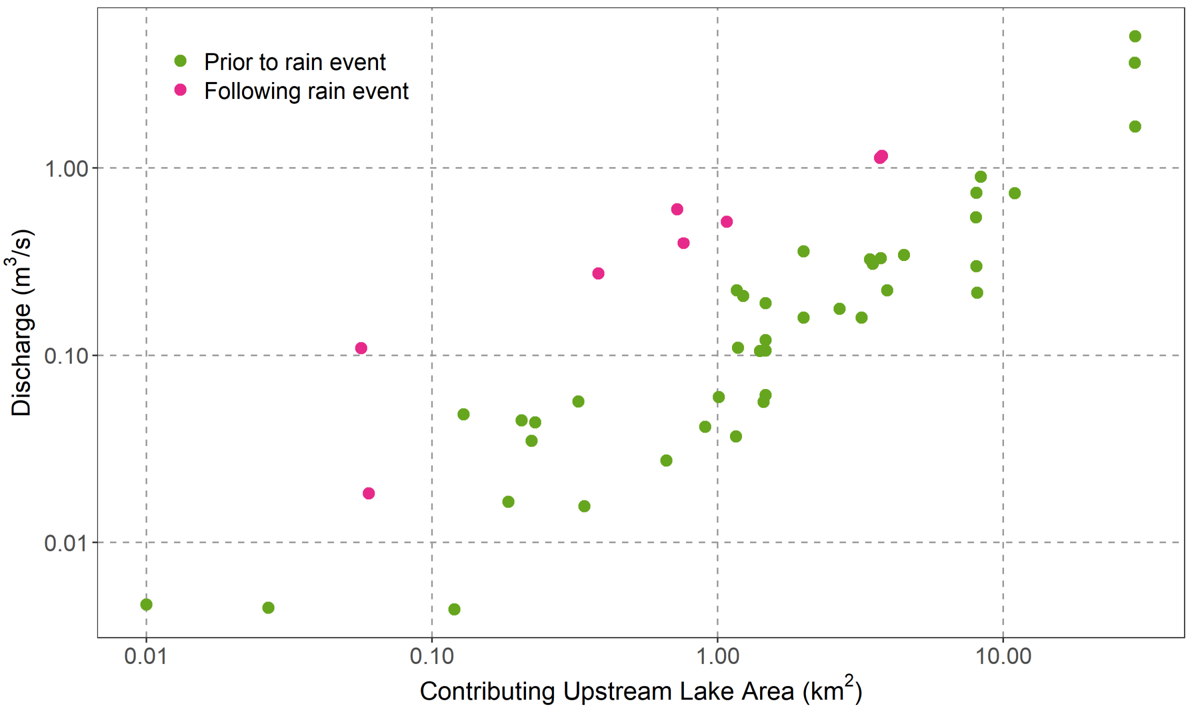

Figure D-1. Correlation between contributing upstream lake area and stream discharge (r = 0.87). A large rain event where 48 mm of rain fell in less than 72 hours occurred between August 3 and August 5, 2019. Green dots represent streams where discharge measures were taken prior to the rain event, while pink dots represent streams where discharge measurements were taken following the rain event. The relative increase in discharge following the rain event suggests that environmental conditions (i.e., periods of rain or drought) confound comparisons of discharge among streams when measurements cannot be taken on the same day or within a short temporal window. Using contributing upstream lake area in place of discharge allowed for a comparison among streams that was more representative of longer-term conditions.

Appendix E: Comparison of covariates across occupancy projects

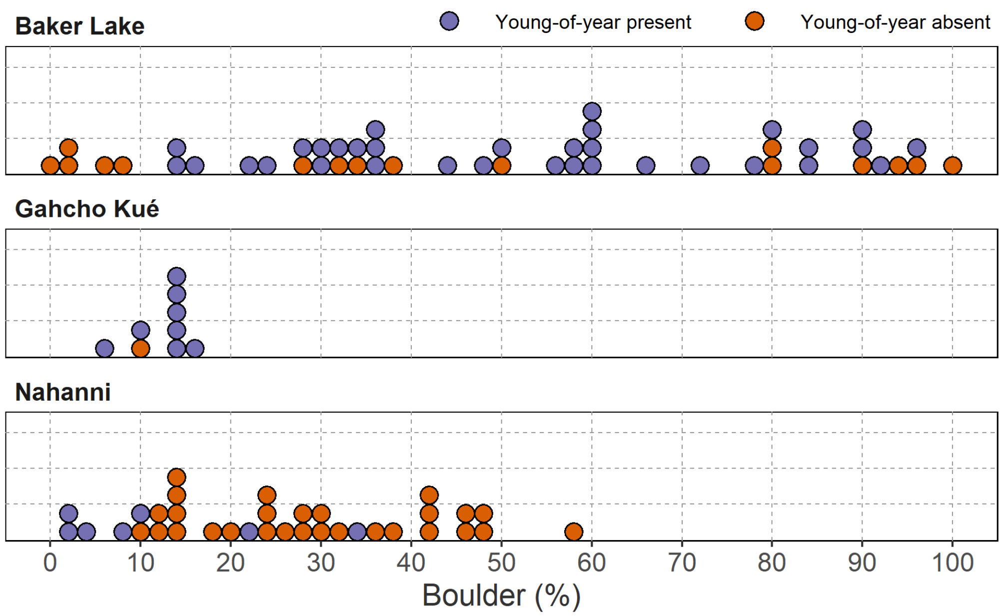

Figure E-1. Distribution of boulder substrate (%) for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream, where purple dots are occupied streams and orange dots are unoccupied streams.

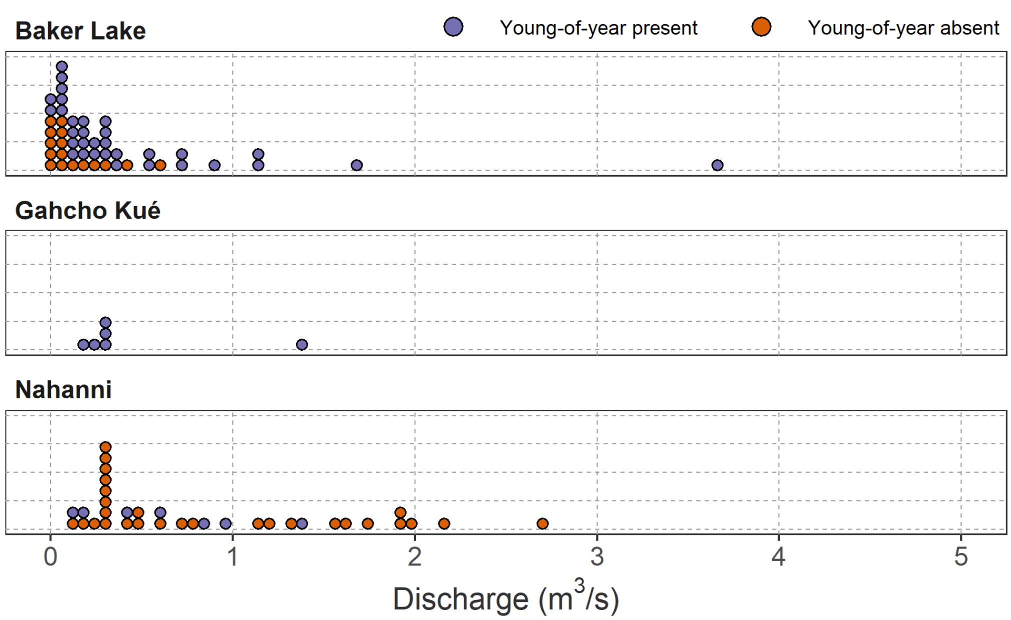

Figure E-2. Distribution of stream discharge for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream, where purple dots are occupied streams and orange dots are unoccupied streams.

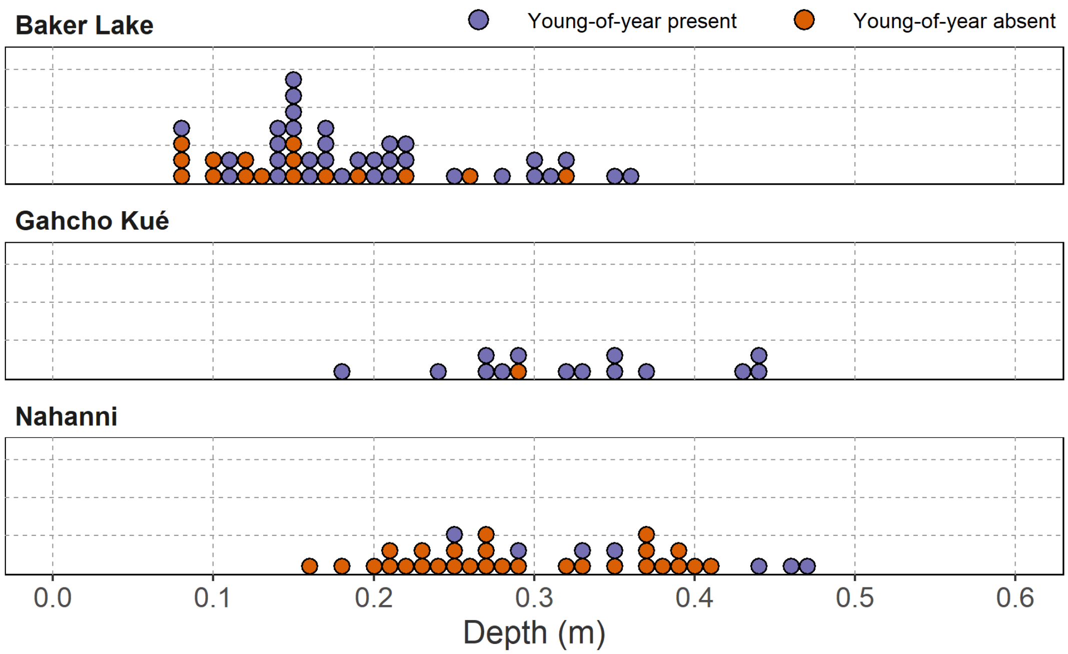

Figure E-3. Distribution of stream depth for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream, where purple dots are occupied streams and orange dots are unoccupied streams.

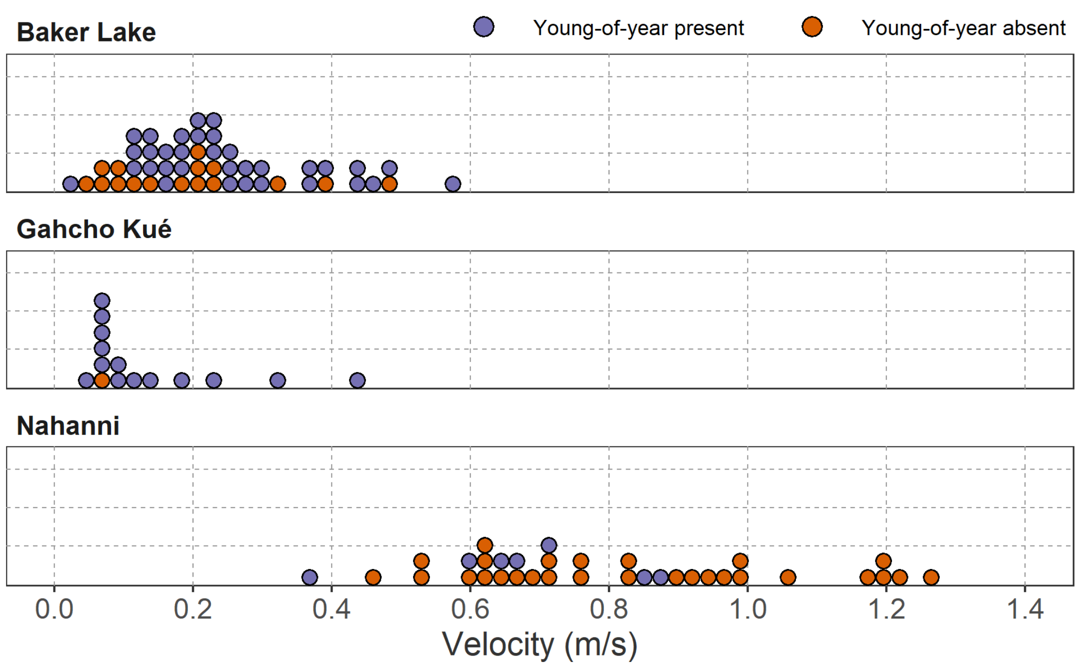

Figure E-4. Distribution of stream velocity for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream, where purple dots are occupied streams and orange dots are unoccupied streams.

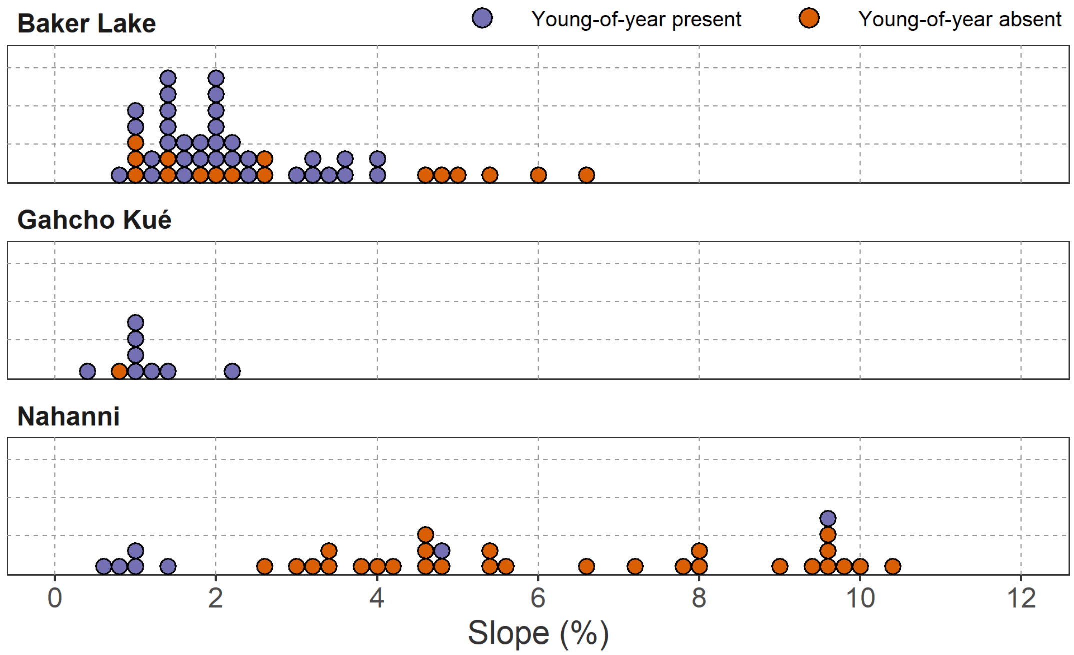

Figure E-5. Distribution of stream slope for various Arctic Grayling YOY occupancy studies. Each dot represents an individual stream, where purple dots are occupied streams and orange dots are unoccupied streams.

Appendix F: Land cover of study area

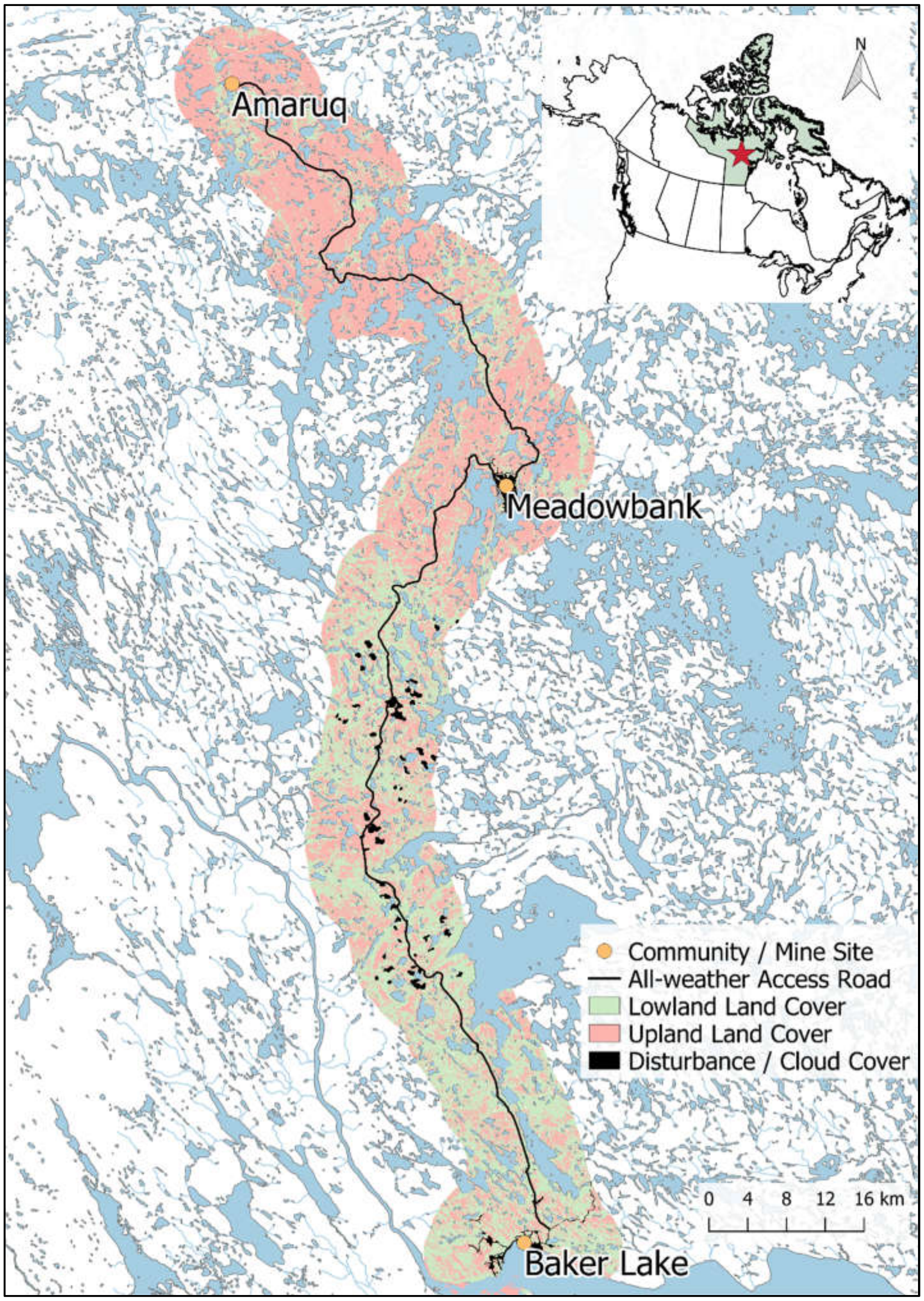

Figure E-6. Lowland and upland land cover within the study area. Between Baker Lake and Meadowbank, lowland land cover dominates the landscape, while upland land cover becomes increasingly common between Meadowbank and Amaruq.

Appendix G: Raw data

Table F-1. Raw data for presence absence surveys.

Stream	Date (2019)	Site Location Latitude (°N)	Site Location Longitude (°E)	Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish) Surveyor 1	Count (# of fish) Surveyor 2
S02	02-Aug	65.360	-96.629	1	09:12	8:00	0	0	0
				2	09:24	8:00	0	0	0
				3	09:35	8:00	0	0	0
				4	09:46	8:00	0	0	0
				5	09:57	8:00	0	0	0
S03	02-Aug	65.316	-96.467	1	12:45	8:00	0	0	0
				2	12:54	8:00	0	0	0
				3	13:04	8:00	0	0	0
				4	13:14	8:00	0	0	0
				5	13:24	8:00	0	0	0
S04	06-Aug	65.313	-96.354	1	09:57	8:00	1	0	3
				2	10:16	8:00	0	0	0
				3	10:26	8:00	1	0	2
				4	10:36	8:00	0	0	0
				5	10:47	8:00	0	0	0
S05	06-Aug	65.309	-96.344	1	12:57	8:00	0	0	0
				2	13:09	8:00	0	0	0
				3	13:21	8:00	0	0	0
				4	13:24	8:00	0	0	0
				5	13:45	8:00	1	1	0
S06	03-Aug	65.304	-96.431	1	11:25	8:00	0	0	0
				2	11:36	8:00	0	0	0
				3	11:46	8:00	0	0	0
				4	11:55	8:00	0	0	0
				5	12:04	8:00	0	0	0
S07	02-Aug	65.302	-96.409	1	16:08	8:00	1	3	2
				2	16:19	5:00	1	3	1
				3	16:26	7:00	1	4	2
				4	16:38	4:00	1	2	1
				5	16:45	4:00	1	2	3
S08	05-Aug	65.300	-96.403	1	08:36	8:00	0	0	0
				2	08:48	8:00	0	0	0
				3	08:58	8:00	0	0	0
				4	09:08	8:00	0	0	0
				5	09:17	8:00	0	0	0
S10	05-Aug	65.250	-96.497	1	12:09	8:00	0	0	0
				2	12:19	8:00	0	0	0
				3	12:28	8:00	0	0	0
				4	12:38	8:00	0	0	0
				5	12:48	8:00	0	0	0
S11	05-Aug	65.208	-96.212	1	15:16	8:00	0	0	0
				2	15:26	8:00	0	0	0
				3	15:38	8:00	0	0	0
				4	15:49	8:00	0	0	0
				5	15:59	8:00	0	0	0

Table F-1. (continued)

Stream	Date (2019)	Site Location		Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish)	
		Latitude (°N)	Longitude (°E)					Surveyor 1	Surveyor 2
S12	07-Aug	65.199	-96.088	1	14:08	8:00	0	0	0
				2	14:17	8:00	0	0	0
				3	14:26	8:00	0	0	0
				4	14:35	8:00	0	0	0
				5	14:45	8:00	0	0	0
S13	07-Aug	65.199	-96.082	1	16:38	8:00	0	0	0
				2	15:43	8:00	0	0	0
				3	15:52	8:00	1	1	0
				4	16:02	8:00	0	0	0
				5	16:13	8:00	0	0	0
S14	07-Aug	65.065	-96.178	1	08:33	8:00	0	0	0
				2	08:44	8:00	0	0	0
				3	08:54	8:00	1	0	1
				4	09:06	8:00	1	1	2
				5	09:16	8:00	0	0	0
S16	04-Aug	64.951	-96.320	1	14:21	8:00	1	2	0
				2	14:32	8:00	1	3	0
				3	14:43	4:30	1	3	1
				4	14:50	5:30	1	1	6
				5	14:58	3:00	1	1	2
S17	04-Aug	64.947	-96.306	1	12:21	8:00	0	0	0
				2	12:31	8:00	0	0	0
				3	12:40	8:00	0	0	0
				4	12:50	8:00	0	0	0
				5	12:59	8:00	0	0	0
S18	31-Jul	64.931	-96.296	1	14:45	8:00	0	0	0
				2	14:55	8:00	0	0	0
				3	15:05	8:00	1	1	0
				4	15:20	8:00	1	1	0
				5	15:35	8:00	0	0	0
S19	04-Aug	64.905	-96.271	1	08:38	8:00	0	0	0
				2	08:47	8:00	0	0	0
				3	08:58	8:00	1	0	3
				4	09:10	8:00	0	0	0
				5	09:19	8:00	1	0	1
S21	30-Jul	64.874	-96.351	1	12:28	3:00	1	7	3
				2	12:36	3:00	1	8	13
				3	12:41	3:00	1	36	25
				4	12:49	3:00	1	20	19
				5	12:54	3:00	1	16	9
S22	30-Jul	64.869	-96.322	1	14:57	3:00	1	1	15
				2	15:02	3:00	1	3	9
				3	15:08	3:00	1	1	6
				4	15:13	3:00	1	6	18
				5	15:23	3:00	1	5	6

Table F-1. (continued)

Stream	Date (2019)	Site Location Latitude (°N)	Site Location Longitude (°E)	Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish) Surveyor 1	Count (# of fish) Surveyor 2
S24	31-Jul	64.850	-96.260	1	10:48	3:00	1	1	5
				2	10:52	3:00	1	1	8
				3	11:00	8:00	1	0	1
				4	11:10	8:00	0	0	0
				5	11:20	8:00	0	0	0
S26	30-Jul	64.828	-96.306	1	09:06	8:00	1	0	1
				2	09:17	8:00	0	0	0
				3	09:29	8:00	1	0	2
				4	09:40	8:00	0	0	0
				5	09:51	8:00	0	0	0
S27	28-Jul	64.826	-96.276	1	13:54	3:00	1	1	3
				2	14:00	8:00	1	0	4
				3	14:12	3:00	1	2	2
				4	14:17	8:00	0	0	0
				5	14:28	8:00	1	1	1
S29	16-Jul	64.665	-96.366	1	09:37	8:06	1	1	15
				2	10:01	8:18	1	1	0
				3	10:15	8:08	1	9	7
				4	10:27	5:04	1	47	37
				5	10:35	4:43	1	1	14
S31	26-Jul	64.644	-96.276	1	15:22	3:00	1	1	3
				2	15:27	3:00	1	19	19
				3	15:33	3:00	1	2	6
				4	15:37	6:00	1	1	1
				5	15:45	8:00	1	1	0
S32	25-Jul	64.623	-96.327	1	12:52	8:00	0	0	0
				2	13:02	8:00	0	0	0
				3	13:12	8:00	0	0	0
				4	13:22	8:00	0	0	0
				5	13:32	8:00	0	0	0
S33	25-Jul	64.611	-96.324	1	10:04	3:00	1	6	5
				2	10:18	3:00	1	2	10
				3	10:23	3:00	1	3	5
				4	10:30	3:00	1	1	26
				5	10:35	3:00	1	2	6
S35	28-Jul	64.579	-96.314	1	09:19	8:00	0	0	0
				2	09:33	8:00	0	0	0
				3	09:43	8:00	0	0	0
				4	09:57	8:00	0	0	0
				5	10:08	8:00	0	0	0
S36	27-Jul	64.524	-96.216	1	15:00	3:00	1	4	2
				2	15:06	3:00	1	1	2
				3	15:12	3:00	1	1	2
				4	15:17	3:00	1	18	17
				5	15:23	3:00	1	14	5

Table F-1. (continued)

Stream	Date (2019)	Site Location		Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish)	
		Latitude (°N)	Longitude (°E)					Surveyor 1	Surveyor 2
S37	27-Jul	64.519	-96.198	1	12:16	3:00	1	7	3
				2	12:22	3:00	1	2	2
				3	12:28	3:00	1	2	7
				4	12:34	3:00	1	9	2
				5	12:40	3:00	1	5	2
S38	19-Jul	64.456	-96.080	1	17:24	3:05	1	3	1
				2	17:30	4:32	1	1	1
				3	17:39	8:00	0	0	0
				4	17:50	8:00	1	1	0
				5	18:02	8:00	0	0	0
S40	20-Jul	64.439	-96.018	1	11:26	8:30	1	1	4
				2	11:36	2:18	1	1	20
				3	11:50	3:00	1	8	7
				4	11:55	3:00	1	4	8
				5	12:00	3:00	1	7	4
S43	18-Jul	64.390	-96.001	1	15:46	8:00	1	2	1
				2	15:59	8:00	0	0	0
				3	16:09	8:00	1	0	2
				4	16:20	8:00	1	1	0
				5	16:31	8:00	1	0	6
S44	18-Jul	64.386	-96.006	1	12:19	6:26	1	13	26
				2	12:29	3:00	1	4	13
				3	12:34	3:03	1	2	3
				4	12:40	8:00	1	2	1
				5	12:52	3:08	1	8	12
S46	17-Jul	64.367	-96.055	1	15:02	8:00	0	0	0
				2	15:13	8:00	0	0	0
				3	15:25	8:30	0	0	0
				4	15:36	8:00	0	0	0
				5	15:48	8:00	0	0	0
S48	01-Aug	65.150	-96.123	1	11:34	8:00	0	0	0
				2	11:44	8:00	0	0	0
				3	11:55	8:00	0	0	0
				4	12:05	8:00	0	0	0
				5	12:15	8:00	0	0	0
S50	16-Jul	64.325	-96.055	1	16:38	7:31	1	1	1
				2	16:54	6:03	1	4	9
				3	17:02	5:31	1	6	4
				4	17:14	5:42	1	5	5
				5	17:21	5:41	1	2	5
S52	29-Jul	64.316	-96.182	1	14:55	8:00	0	0	0
				2	15:04	8:00	0	0	0
				3	15:13	8:00	0	0	0
				4	15:21	8:00	0	0	0
				5	15:30	8:00	0	0	0

Table F-1. (continued)

Stream	Date (2019)	Site Location Latitude (°N)	Site Location Longitude (°E)	Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish) Surveyor 1	Count (# of fish) Surveyor 2
S53	29-Jul	64.312	-96.210	1	10:31	3:00	1	3	18
				2	10:40	3:00	1	19	26
				3	10:46	3:00	1	18	23
				4	10:50	3:00	1	3	14
				5	10:55	3:10	1	12	7
S54	29-Jul	64.308	-96.222	1	08:33	3:00	1	3	5
				2	08:40	3:00	1	4	2
				3	08:45	3:00	1	5	8
				4	08:51	3:00	1	2	5
				5	08:57	3:00	1	5	2
S57	17-Jul	64.290	-95.851	1	08:57	8:00	0	0	0
				2	09:08	8:00	0	0	0
				3	09:18	8:00	0	0	0
				4	09:28	8:00	0	0	0
				5	09:42	8:00	0	0	0
S58	26-Jul	64.646	-96.343	1	11:12	8:00	1	0	1
				2	11:24	8:00	0	0	0
				3	11:38	8:00	0	0	0
				4	11:54	8:00	1	1	1
				5	12:05	8:00	1	1	1
S59	25-Jul	64.639	-96.329	1	16:38	3:00	1	1	2
				2	16:44	4:00	1	2	1
				3	16:50	6:00	1	1	6
				4	17:01	5:00	1	6	2
				5	17:10	8:00	1	0	4
S60	19-Jul	64.463	-96.096	1	13:36	8:00	1	19	1
				2	13:48	3:00	1	1	1
				3	13:53	8:00	1	11	1
				4	14:04	3:00	1	3	5
				5	14:09	3:00	1	11	4
S62	01-Aug	65.157	-96.149	1	14:51	8:00	0	0	0
				2	15:01	8:00	0	0	0
				3	15:11	8:00	0	0	0
				4	15:21	8:00	0	0	0
				5	16:27	8:00	0	0	0
S63	18-Jul	64.386	-96.026	1	08:10	5:06	1	2	14
				2	08:19	3:08	1	16	11
				3	08:25	3:48	1	3	7
				4	08:33	3:38	1	22	25
				5	08:42	3:10	1	43	4
S64	29-Jul	64.314	-96.205	1	12:54	3:00	1	22	39
				2	12:59	3:00	1	11	26
				3	13:04	3:00	1	29	30
				4	13:09	3:00	1	5	32
				5	13:15	3:00	1	11	15

Table F-1. (continued)

Stream	Date (2019)	Site Location		Replicate	Start Time (hh:mm)	Search Time (mm:ss)	Presence / Absence	Count (# of fish)	
		Latitude (°N)	Longitude (°E)					Surveyor 1	Surveyor 2
S65	03-Aug	65.300	-96.409	1	14:43	8:00	0	0	0
				2	14:54	8:00	0	0	0
				3	15:04	8:00	0	0	0
				4	15:14	8:00	0	0	0
				5	15:25	8:00	0	0	0
S66	19-Jul	64.471	-96.109	1	10:16	8:00	0	0	0
				2	10:27	8:00	1	0	2
				3	10:40	8:00	0	0	0
				4	10:52	8:00	1	0	2
				5	11:02	8:00	1	0	2
S67	27-Jul	64.513	-96.193	1	09:12	8:00	1	1	2
				2	09:23	8:00	1	2	0
				3	09:35	8:00	1	0	4
				4	09:45	4:30	1	3	4
				5	09:52	5:00	1	3	1
S70	20-Jul	64.494	-96.103	1	15:18	7:00	1	12	10
				2	15:28	3:00	1	1	8
				3	15:35	3:00	1	12	8
				4	15:42	3:00	1	5	3
				5	15:47	3:00	1	3	3

Table F-2. Detection covariates for each replicate at each site (stream).

Stream	Cloud Cover (%)	Rain	Wetted Width (m)	# of Channels	Slope (%)	Instream Vegetation (%)	Overhanging Vegetation (%)	Undercut Bank (%)	Depth (m)	Velocity (m/s)	Substrate						
											Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)	Sand (%)	Fines (%)	Organics (%)
S02	0	N	60	1	0.9	0	0	0	0.29	0.03	0	100	0	0	0	0	0
	0	N	31	1	3.5	0	0	0	0.42	0.06	0	100	0	0	0	0	0
	0	N	38	1	1.0	0	0	0	0.32	0.05	0	100	0	0	0	0	0
	0	N	84	1	1.0	0	0	0	0.36	0.04	0	100	0	0	0	0	0
	0	N	88	1	0.8	0	0	0	0.22	0.02	0	100	0	0	0	0	0
S03	0	N	2.41	3	1.2	3	0	0	0.20	0.10	0	10	5	10	10	0	65
	0	N	2.91	3	2.0	6	0	0	0.16	0.18	0	45	5	5	5	0	40
	0	N	2.70	3	3.5	5	1	0	0.21	0.17	0	40	0	0	10	0	50
	0	N	4.38	3	1.0	8	2	0	0.12	0.33	0	35	0	5	5	0	55
	0	N	4.29	4	2.5	4	1	0	0.14	0.29	0	40	10	8	7	0	35
S04	100	N	42.60	3	4.0	25	1	0	0.26	0.64	0	30	20	0	5	0	45
	100	N	16.35	4	3.2	20	0	0	0.28	0.60	0	40	35	10	0	0	15
	100	N	17.60	2	2.1	25	0	0	0.24	0.41	0	20	35	15	5	0	25
	100	N	12.89	2	1.2	30	0	0	0.38	0.32	0	10	20	30	10	0	30
	100	N	10.40	1	1.4	50	0	0	0.36	0.30	0	20	15	30	20	0	15
S05	60	N	26.30	1	1.7	35	0	0	0.40	0.20	0	70	10	0	0	0	20
	70	N	35.30	1	2.0	28	0	0	0.39	0.25	0	75	10	0	0	0	15
	70	N	17.31	1	2.0	25	4	0	0.30	0.35	0	75	10	0	0	0	15
	70	N	11.30	1	2.0	18	10	0	0.33	0.40	0	100	0	0	0	0	0
	70	N	18.07	1	2.5	5	10	0	0.35	0.58	0	100	0	0	0	0	0
S06	100	L	3.70	4	4.0	0	12	0	0.10	0.12	0	95	5	0	0	0	0
	100	L	12.50	4	5.0	0	3	0	0.08	0.14	0	95	5	0	0	0	0
	100	L	14.22	4	4.8	0	0	0	0.10	0.14	0	100	0	0	0	0	0
	100	L	12.20	5	6.0	1	0	0	0.10	0.30	0	90	10	0	0	0	0
	100	L	8.02	4	10.5	0	1	0	0.13	0.21	0	95	3	0	0	0	2
S07	0	N	10.80	6	4.5	2	5	0	0.11	0.41	0	95	5	0	0	0	0
	0	N	11.75	5	4.2	4	4	0	0.19	0.51	0	85	15	0	0	0	0
	0	N	4.66	4	4.0	6	7	0	0.13	0.36	0	85	15	0	0	0	0
	0	N	11.35	5	4.0	6	5	0	0.17	0.39	0	95	5	0	0	0	0
	0	N	13.98	6	3.0	7	3	0	0.12	0.49	0	90	10	0	0	0	0
S08	100	L	28	1	2.0	1	2	0	0.16	0.21	0	75	25	0	0	0	0
	100	L	40	1	2.1	0	1	0	0.16	0.35	0	90	10	0	0	0	0
	100	L	38	1	2.0	0	3	0	0.24	0.16	0	95	5	0	0	0	0
	100	L	19	1	1.8	0	1	0	0.26	0.13	0	95	5	0	0	0	0
	100	L	22	2	1.0	0	1	0	0.28	0.15	0	95	5	0	0	0	0
S10	100	N	6.65	3	8.0	30	0	0	0.09	0.43	0	2	0	3	0	0	95
	100	N	6.25	3	8.0	40	0	0	0.10	0.69	0	3	0	0	0	0	97
	100	N	11.15	2	6.0	40	0	0	0.16	0.33	0	30	0	0	0	0	70
	100	N	8.05	2	6.0	45	2	0	0.10	0.56	0	3	0	0	0	0	97
	100	N	3.74	2	5.0	60	0	0	0.13	0.36	0	0	3	2	0	0	95
S11	100	N	24.50	2	4.5	5	40	0	0.22	0.18	0	100	0	0	0	0	0
	100	N	22.42	3	4.5	8	65	0	0.19	0.34	0	100	0	0	0	0	0
	100	N	60	2	5.0	10	70	0	0.21	0.22	0	100	0	0	0	0	0
	100	L	22	4	5.0	15	70	0	0.21	0.59	0	100	0	0	0	0	0
	100	L	14.05	4	5.5	4	6	0	0.15	0.63	0	85	15	0	0	0	0
S12	0	N	1.20	2	2.0	10	0	0	0.09	0.25	0	10	35	20	0	0	35
	20	N	5.74	2	2.0	25	0	0	0.09	0.14	0	0	0	0	35	0	65
	20	N	4.95	2	1.5	30	0	0	0.10	0.13	0	0	0	0	5	0	95
	20	N	1.20	2	1.0	15	0	0	0.21	0.08	0	0	0	0	5	0	95
	30	N	0.89	1	1.0	10	0	0	0.27	0.09	0	0	0	0	5	0	95
S13	100	N	17.90	4	4.0	18	1	0	0.19	0.37	0	40	25	0	0	0	35
	0	N	18.03	4	4.0	12	1	0	0.19	0.55	0	40	30	0	0	0	30
	0	N	11.96	3	2.8	12	3	0	0.22	0.45	0	35	30	5	0	0	30
	0	N	10.40	3	2.0	15	3	0	0.22	0.26	0	35	30	5	0	0	30
	60	N	16.53	2	2.0	15	0	0	0.18	0.26	0	35	25	3	2	0	35
S14	0	N	5.57	1	2.0	0	6	0	0.23	0.44	0	85	15	0	0	0	0
	0	N	4.73	1	7.0	0	25	0	0.17	0.61	0	95	5	0	0	0	0
	0	N	8.35	1	1.8	1	2	0	0.25	0.31	0	90	10	0	0	0	0
	0	N	5.84	1	4.0	3	2	0	0.27	0.57	0	90	10	0	0	0	0
	0	N	10.95	1	3.0	5	0	0	0.20	0.50	0	95	5	0	0	0	0

Table F-2. (continued)

Stream	Cloud Cover (%)	Rain	Wetted Width (m)	# of Channels	Slope (%)	Instream Vegetation (%)	Overhanging Vegetation (%)	Undercut Bank (%)	Depth (m)	Velocity (m/s)	Substrate: Bedrock (%)	Substrate: Boulder (%)	Substrate: Cobble (%)	Substrate: Gravel (%)	Substrate: Sand (%)	Substrate: Fines (%)	Substrate: Organics (%)
S16	100	H	9.39	1	1.2	12	0	0	0.18	0.13	0	35	35	15	10	5	0
	100	H	8.25	1	1.4	8	0	0	0.16	0.12	0	60	35	5	0	0	0
	100	M	12.78	1	1.5	10	0	0	0.14	0.17	0	65	35	0	0	0	0
	100	M	10.40	2	2.0	10	0	0	0.18	0.17	0	70	30	0	0	0	0
	100	M	5.56	3	2.0	8	0	0	0.29	0.18	0	70	25	5	0	0	0
S17	100	L	0.73	1	1.5	20	0	0	0.19	0.36	0	3	10	4	3	0	80
	100	L	5.80	1	1.0	35	0	0	0.11	0.05	0	2	0	0	0	0	98
	100	L	7.82	1	0.9	20	0	0	0.19	0.02	0	2	0	0	0	0	98
	100	L	8.36	1	0.9	30	0	0	0.11	0.11	0	2	0	0	0	0	98
	100	M	5.30	1	0.8	30	0	0	0.17	0.05	0	0	0	0	0	0	100
S18	100	N	2.54	1	1.5	1	0	1	0.27	0.23	0	65	30	5	0	0	0
	100	N	3.61	1	3.0	2	0	0	0.23	0.29	0	50	35	15	0	0	0
	100	N	2.59	1	1.0	4	0	0	0.18	0.40	0	45	35	20	0	0	0
	100	N	3.67	1	1.4	4	0	2	0.14	0.32	0	50	30	20	0	0	0
	100	N	3.50	1	1.2	3	0	0	0.22	0.28	0	40	40	20	0	0	0
S19	100	N	7.79	1	3.8	1	0	0	0.08	0.17	0	60	40	0	0	0	0
	100	N	9.51	1	3.5	1	0	0	0.11	0.21	0	60	35	5	0	0	0
	100	N	10.24	1	4.0	1	0	0	0.11	0.19	0	65	35	0	0	0	0
	100	L	10.67	1	3.0	2	0	0	0.10	0.26	0	85	15	0	0	0	0
	100	L	10.77	2	4.0	3	0	0	0.17	0.17	0	90	10	0	0	0	0
S21	0	N	2.65	2	1.4	5	0	0	0.12	0.17	0	85	10	5	0	0	0
	0	N	4.50	4	1.0	4	0	0	0.16	0.11	0	90	10	0	0	0	0
	0	N	7.60	4	1.0	2	4	0	0.12	0.14	0	85	15	0	0	0	0
	0	N	3.35	2	1.1	5	0	0	0.14	0.14	0	65	35	0	0	0	0
	0	N	9.42	3	1.2	4	0	6	0.17	0.12	0	63	32	5	0	0	0
S22	60	N	3.52	2	2.0	6	1	0	0.24	0.16	0	30	30	10	5	0	25
	70	N	4.14	3	2.5	10	1	0	0.16	0.16	0	15	20	5	0	0	60
	80	N	0.80	1	2.0	8	0	0	0.19	0.22	0	15	30	30	10	0	15
	80	N	3.04	1	3.5	10	0	0	0.52	0.02	0	10	25	20	25	0	20
	60	N	2.91	2	2.0	12	0	0	0.28	0.07	0	10	20	30	10	0	30
S24	100	N	33	1	1.6	2	0	0	0.11	0.17	0	40	30	30	0	0	0
	100	N	20.19	1	1.1	4	0	0	0.06	0.10	0	30	35	35	0	0	0
	100	N	26	1	1.8	12	0	0	0.08	0.16	0	30	35	30	5	0	0
	100	N	22	1	1.0	12	0	0	0.08	0.10	0	30	35	30	5	0	0
	100	N	46	1	1.0	12	0	0	0.07	0.06	0	30	35	20	10	5	0
S26	0	N	33.84	1	1.0	6	0	0	0.20	0.10	0	50	40	10	0	0	0
	0	N	37	1	1.1	6	0	0	0.19	0.11	0	25	60	15	0	0	0
	0	N	23	1	2.0	0	1	0	0.06	0.22	0	55	40	5	0	0	0
	0	N	28	1	4.0	0	5	0	0.11	0.25	0	50	45	5	0	0	0
	0	N	40	1	2.7	0	4	0	0.17	0.11	0	60	35	5	0	0	0
S27	70	N	36	1	2.5	3	0	0	0.12	0.36	0	60	40	0	0	0	0
	60	N	54	1	2.2	3	0	0	0.14	0.15	0	50	30	20	0	0	0
	50	N	49	1	2.1	3	0	0	0.13	0.15	0	60	25	15	0	0	0
	70	N	45	1	2.0	4	0	0	0.17	0.16	0	70	20	10	0	0	0
	100	L	38	1	1.5	5	0	0	0.18	0.20	0	65	25	10	0	0	0
S29	5	N	11.67	4	2.2	7	5	2	0.32	0.42	0	25	35	40	0	0	0
	5	N	7.78	3	2.8	5	5	2	0.23	0.29	0	45	40	10	0	0	5
	0	N	10.24	4	2.4	7	7	5	0.22	0.40	0	35	40	20	0	0	5
	20	N	6.70	2	1.8	5	15	5	0.21	0.44	0	15	65	20	0	0	0
	25	N	4.06	1	2.3	2	15	2	0.29	0.44	0	35	50	15	0	0	0
S31	100	N	1.03	2	1.3	4	0	3	0.25	0.11	0	5	20	10	5	0	60
	100	N	2.97	3	0.9	7	0	4	0.15	0.21	0	10	20	15	10	0	45
	100	N	2.55	2	1.2	5	0	2	0.26	0.06	0	25	25	15	5	0	30
	100	N	1.19	2	1.0	6	0	2	0.19	0.17	0	15	35	15	5	0	30
	100	N	3.13	2	1.0	6	0	4	0.19	0.19	0	15	20	10	10	0	45
S32	100	L	1.07	1	1.2	4	0	2	0.10	0.18	0	15	40	30	0	0	15
	100	L	2.12	2	1.2	4	0	6	0.25	0.09	0	7	60	20	0	0	13
	90	L	2.18	2	1.2	2	1	0	0.15	0.07	0	20	35	30	5	0	10
	40	N	2.69	2	1.1	2	1	0	0.12	0.09	0	55	20	15	3	0	7
	60	N	1.17	1	0.7	1	0	0	0.12	0.07	0	65	15	5	0	0	15

Table F-2. (continued)

Stream	Cloud Cover (%)	Rain	Wetted Width (m)	# of Channels	Slope (%)	Instream Vegetation (%)	Overhanging Vegetation (%)	Undercut Bank (%)	Depth (m)	Velocity (m/s)	Substrate						
											Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)	Sand (%)	Fines (%)	Organics (%)
S33	40	N	0.77	1	4.5	1	90	40	0.14	0.11	0	35	15	35	7	0	8
	40	N	0.65	1	1.5	0	65	0	0.14	0.49	0	40	25	20	5	0	10
	75	N	1.95	2	1.0	20	35	0	0.16	0.14	0	45	10	10	10	0	25
	80	L	0.85	2	5.2	15	45	0	0.21	0.11	0	25	0	15	20	0	40
	25	N	0.74	1	4.0	35	50	0	0.16	0.11	0	25	15	25	0	0	35
S35	100	N	0.81	1	3.0	1	0	0	0.11	0.06	0	15	45	35	0	0	5
	100	N	1.11	1	6.0	0	2	0	0.10	0.04	0	60	35	5	0	0	0
	100	N	0.84	1	6.0	8	6	0	0.08	0.07	0	50	35	10	0	0	5
	100	N	1.33	2	5.0	45	2	0	0.04	0.12	0	60	5	5	0	0	30
	100	N	1.17	2	5.2	40	1	0	0.10	0.04	0	3	4	3	0	0	90
S36	100	N	57	1	0.9	0	1	0	0.16	0.08	0	65	25	5	5	0	0
	100	N	42	1	1.0	1	0	0	0.22	0.11	0	65	25	5	5	0	0
	100	N	42	2	1.3	0	0	0	0.12	0.13	0	75	25	0	0	0	0
	100	N	28	2	2.1	1	1	0	0.12	0.25	0	40	40	20	0	0	0
	100	N	39	2	1.8	2	1	0	0.14	0.26	0	50	35	15	0	0	0
S37	100	L	18.80	1	2.0	3	0	0	0.14	0.17	0	20	30	40	10	0	0
	100	L	28	1	2.2	4	0	0	0.08	0.27	0	35	40	25	0	0	0
	100	L	19	1	1.2	3	0	0	0.11	0.21	0	30	35	35	0	0	0
	100	L	28	1	1.0	5	0	0	0.11	0.14	0	30	35	35	0	0	0
	100	L	17.32	1	1.0	8	0	0	0.12	0.17	0	30	35	35	0	0	0
S38	0	N	16	2	1.7	3	8	0	0.11	0.47	0	35	30	35	0	0	0
	0	N	9	1	1.8	5	0	0	0.25	0.27	0	35	35	30	0	0	0
	0	N	9	1	1.4	15	0	0	0.24	0.39	0	30	30	40	0	0	0
	0	N	33	1	1.4	20	0	0	0.15	0.14	0	40	30	30	0	0	0
	0	N	13.60	1	0.9	18	0	0	0.25	0.08	0	40	30	30	0	0	0
S40	0	N	13.50	2	2.4	6	1	0	0.20	0.20	0	65	25	10	0	0	0
	0	N	13.00	4	1.8	12	4	0	0.21	0.16	0	65	25	3	0	0	7
	0	N	8.00	3	2.0	15	5	0	0.09	0.24	0	50	30	20	0	0	0
	0	N	3.04	1	2.6	2	15	4	0.11	0.46	0	60	35	5	0	0	0
	0	N	4.08	1	1.1	7	0	0	0.21	0.18	0	60	35	5	0	0	0
S43	0	N	8.04	1	2.0	3	0	0	0.32	0.44	0	40	30	25	5	0	0
	0	N	8	1	0.9	2	0	1	0.48	0.74	0	35	25	20	5	0	15
	0	N	16	1	1.5	2	0	0	0.31	0.49	0	50	40	10	0	0	0
	0	N	29	2	2.5	4	4	0	0.20	0.70	0	90	10	0	0	0	0
	0	N	24	2	3.0	4	4	0	0.25	0.53	0	80	20	0	0	0	0
S44	10	N	44	1	2.1	2	0	0	0.33	0.33	0	75	25	0	0	0	0
	0	N	44	1	2.0	1	0	0	0.23	0.50	0	55	45	0	0	0	0
	0	N	49	1	1.8	5	0	0	0.29	0.46	0	60	35	5	0	0	0
	30	N	44	1	1.7	10	6	0	0.26	0.34	0	60	35	5	0	0	0
	30	N	29	1	1.2	6	10	0	0.37	0.59	0	50	40	10	0	0	0
S46	100	N	0.74	1	1.2	5	2	0	0.20	0.39	0	50	20	10	0	0	20
	100	N	0.92	1	1.1	5	0	0	0.27	0.20	0	60	20	15	0	0	5
	100	N	0.86	1	1.1	4	2	0	0.21	0.23	0	40	30	20	0	0	10
	100	N	1.20	1	0.9	15	2	0	0.23	0.15	0	40	30	25	0	0	5
	80	N	0.94	1	0.8	8	0	0	0.37	0.14	0	60	20	10	0	0	10
S48	0	N	20.05	1	1.9	4	0	0	0.09	0.18	0	75	20	5	0	0	0
	0	N	9.49	1	2.9	2	0	0	0.16	0.26	0	95	5	0	0	0	0
	0	N	5.72	1	2.6	3	0	0	0.14	0.42	0	95	5	0	0	0	0
	0	N	13.53	1	2.2	4	0	0	0.04	0.16	0	75	25	0	0	0	0
	0	N	20.92	1	1.6	2	0	0	0.07	0.14	0	65	30	5	0	0	0
S50	0	N	2.25	1	3.9	12	1	0	0.18	0.31	0	45	35	20	0	0	0
	0	N	2.34	1	4.4	6	0	0	0.14	0.19	0	40	45	15	0	0	0
	0	N	2.26	1	4.1	12	1	0	0.12	0.24	0	60	25	15	0	0	0
	0	N	1.46	1	3.9	6	2	0	0.21	0.19	0	35	55	10	0	0	0
	0	N	1.58	1	4.0	8	0	0	0.23	0.19	0	45	40	15	0	0	0
S52	30	N	0.76	1	4.0	65	0	0	0.05	0.13	0	0	0	0	0	0	100
	0	N	0.37	1	3.0	60	0	0	0.04	0.12	0	0	0	0	0	0	100
	10	N	0.40	1	3.0	65	0	0	0.05	0.15	0	0	0	0	0	0	100
	50	N	0.91	1	2.3	65	0	0	0.14	0.03	0	0	0	0	0	0	100
	40	N	1.41	1	1.0	70	0	0	0.12	0.04	0	0	0	0	0	0	100

Table F-2. (continued)

Stream	Cloud Cover (%)	Rain	Wetted Width (m)	# of Channels	Slope (%)	Instream Vegetation (%)	Overhanging Vegetation (%)	Undercut Bank (%)	Depth (m)	Velocity (m/s)	Substrate Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)	Sand (%)	Fines (%)	Organics (%)
S53	90	N	2.67	2	1.5	12	0	4	0.18	0.22	0	15	35	30	20	0	0
	70	N	2.02	2	1.8	18	1	4	0.18	0.22	0	15	35	30	20	0	0
	50	N	2.68	2	2.0	15	1	3	0.21	0.28	0	35	45	15	5	0	0
	60	N	6.71	2	2.0	35	1	3	0.16	0.28	0	40	40	15	3	0	2
	60	N	5.20	2	1.9	35	0	2	0.12	0.13	0	45	35	15	5	0	0
S54	50	N	4.14	1	3.2	6	4	0	0.11	0.37	0	60	35	5	0	0	0
	60	N	4.54	1	4.8	1	2	0	0.17	0.31	0	65	30	5	0	0	0
	60	N	2.85	1	2.0	3	1	0	0.22	0.18	0	65	30	5	0	0	0
	70	N	3.08	1	3.8	4	1	0	0.16	0.32	0	70	25	5	0	0	0
	80	N	2.91	1	3.0	2	0	0	0.17	0.37	0	75	20	5	0	0	0
S57	100	N	6.10	1	3.2	0	0	0	0.06	0.33	0	20	35	45	0	0	0
	100	N	6.99	1	2.2	0	0	0	0.05	0.18	0	10	40	50	0	0	0
	100	N	3.12	1	4.4	0	0	0	0.08	0.11	3	25	35	37	0	0	0
	100	N	2.70	1	9.0	3	15	0	0.11	0.30	35	35	20	10	0	0	0
	50	N	3.30	4	8.2	3	30	0	0.09	0.16	0	50	35	15	0	0	0
S58	100	N	47	1	0.5	6	0	0	0.26	0.01	0	98	2	0	0	0	0
	100	L	35	1	0.9	8	0	0	0.20	0.02	0	95	5	0	0	0	0
	100	L	25	1	0.7	3	0	0	0.22	0.03	0	95	5	0	0	0	0
	100	L	25	1	0.7	1	0	0	0.21	0.02	0	98	2	0	0	0	0
	100	L	19.10	1	0.8	1	0	0	0.20	0.02	0	95	5	0	0	0	0
S59	0	N	19	3	1.9	10	1	0	0.14	0.09	0	75	20	5	0	0	0
	0	N	17	2	1.7	6	0	0	0.18	0.06	0	80	20	0	0	0	0
	0	N	18.25	4	1.1	4	1	0	0.14	0.13	0	85	15	0	0	0	0
	0	N	30.50	3	2.5	3	3	0	0.08	0.17	0	80	12	8	0	0	0
	60	N	15	1	0.9	6	2	0	0.16	0.13	0	85	15	0	0	0	0
S60	100	N	23	9	2.5	8	60	0	0.25	0.29	0	65	20	5	5	0	5
	100	N	23	5	2.1	12	65	0	0.15	0.17	0	70	20	0	0	0	10
	100	N	10.50	4	2.1	5	35	0	0.22	0.34	0	65	30	5	0	0	0
	100	N	13	3	1.9	2	40	0	0.16	0.25	0	40	30	30	0	0	0
	95	N	6.14	1	1.7	4	20	0	0.25	0.21	0	40	35	25	0	0	0
S62	10	N	0.75	1	4.1	15	5	0	0.09	0.08	0	20	0	0	0	0	80
	0	N	0.79	2	3.5	20	2	0	0.11	0.08	0	5	0	0	0	0	95
	10	N	0.85	1	3.0	30	0	0	0.12	0.10	0	5	0	0	0	0	95
	0	N	1.80	1	1.0	12	0	0	0.14	0.05	0	0	0	0	3	0	97
	0	N	0.82	1	1.0	5	0	0	0.11	0.06	0	0	0	0	3	0	97
S63	100	N	55	1	1.0	4	0	0	0.30	0.31	0	40	35	25	0	0	0
	50	N	58	2	0.9	1	0	0	0.34	0.26	0	25	40	35	0	0	0
	0	N	95	2	2.0	1	0	0	0.26	0.29	0	35	35	30	0	0	0
	0	N	106	3	2.0	1	1	0	0.27	0.17	0	45	30	25	0	0	0
	50	N	81	1	1.4	1	1	0	0.41	0.17	0	40	35	25	0	0	0
S64	75	N	13.39	2	1.0	20	0	7	0.12	0.08	0	25	20	15	0	0	40
	60	N	13.51	2	1.2	15	1	7	0.16	0.13	0	20	20	15	0	0	45
	70	N	14.47	2	1.0	25	2	2	0.11	0.09	0	15	25	10	0	0	50
	20	N	8.52	2	1.8	15	0	10	0.24	0.04	0	15	25	5	5	0	50
	20	N	1.34	1	1.6	0	0	5	0.20	0.28	0	35	30	25	10	0	0
S65	100	N	1.54	3	5.0	5	2	0	0.08	0.51	0	65	0	0	0	0	35
	100	N	0.92	3	5.0	6	10	0	0.20	0.26	0	85	0	0	0	0	15
	100	L	1.36	2	4.8	4	8	0	0.09	0.29	0	95	0	0	0	0	5
	100	N	1.89	3	4.0	5	12	0	0.14	0.27	0	90	0	0	0	0	10
	100	N	2.58	3	4.0	8	18	0	0.13	0.31	0	70	10	0	0	0	20
S66	90	N	2.86	1	1.2	1	7	50	0.26	0.42	0	15	45	35	5	0	0
	95	N	3.36	1	1.0	0	4	70	0.26	0.40	0	15	60	25	0	0	0
	100	N	2.98	1	1.1	1	15	75	0.39	0.30	0	10	45	35	5	0	5
	100	N	8.15	1	0.7	2	12	20	0.53	0.08	0	10	40	35	0	0	15
	0	N	5.10	1	1.0	1	2	10	0.32	0.19	0	20	44	30	1	0	5
S67	100	N	22	2	3.1	1	7	0	0.20	0.15	5	95	0	0	0	0	0
	100	L	22	2	4.2	0	15	0	0.14	0.33	10	85	5	0	0	0	0
	100	N	20	2	4.0	2	20	0	0.17	0.25	20	80	0	0	0	0	0
	100	L	19	2	3.0	4	12	0	0.20	0.21	0	85	15	0	0	0	0
	100	L	16.10	1	1.8	15	15	0	0.08	0.30	0	80	20	0	0	0	0
S70	0	N	52	1	1.9	0	0	0	0.18	0.20	0	95	5	0	0	0	0
	0	N	54	1	2.0	0	0	0	0.08	0.14	0	95	5	0	0	0	0
	0	N	60	1	1.9	1	0	0	0.16	0.17	0	90	10	0	0	0	0
	0	N	57	1	2.4	0	0	0	0.19	0.18	0	90	10	0	0	0	0
	0	N	61	1	2.2	0	0	0	0.15	0.27	0	90	10	0	0	0	0

Table F-3. Water quality and water temperature occupancy covariates for each site (stream).

Stream	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat)	Specific Conductivity (µS/cm)	pH (pH units)	Water Temperature (°C)[†]				
					Mean Daily Min	Mean Daily Max	Mean Daily Range	Mean Daily CV	ATU
S02	10.00	97.3	19.1	7.55	10.61	13.09	2.33	6.83	105,816
S03	9.86	100.0	25.1	6.81	10.08	13.63	3.46	9.65	105,474
S04	10.70	98.7	20.0	6.95	11.14	13.64	2.35	6.29	110,679
S05	10.70	99.5	22.9	7.08	11.11	14.09	2.86	7.60	112,283
S06	9.73	91.8	19.6	7.51	10.63	13.02	2.08	6.22	105,213
S07	9.97	102.6	22.6	7.07	10.65	13.39	2.65	7.31	107,279
S08	10.50	96.1	39.1	5.70	10.33	12.70	1.98	6.29	101,721
S10	10.60	94.8	13.1	6.21	8.78	14.06	5.48	15.71	100,703
S11	10.10	92.7	21.2	6.46	9.61	13.68	3.90	11.33	102,783
S12	9.21	95.4	21.1	6.17	7.98	15.87	7.34	21.15	101,814
S13	9.93	97.4	31.0	6.86	9.86	14.06	4.09	11.63	106,028
S14	10.40	94.8	41.7	7.17	10.49	12.71	2.25	6.55	104,272
S16	10.80	96.6	13.2	6.35	9.07	12.55	3.56	11.46	97,261
S17	10.40	94.7	15.1	6.19	9.47	15.46	6.00	16.23	109,439
S18	10.10	97.3	15.2	7.03	11.08	13.97	3.04	7.96	112,588
S19	10.80	97.6	17.4	6.70	10.55	13.59	2.94	8.17	108,133
S21	9.81	98.8	26.0	6.75	10.72	14.09	3.64	9.61	111,784
S22	9.63	95.2	25.0	6.50	10.79	13.97	3.18	8.60	111,142
S24	10.50	99.4	26.7	7.21	9.45	13.26	3.03	9.25	97,538
S26	10.40	98.1	20.1	7.37	10.66	13.45	2.54	7.28	107,617
S27	10.90	101.3	20.9	7.05	11.31	13.28	1.84	4.90	110,114
S29	9.16	92.4	70.5	7.21	10.28	13.67	3.31	9.42	107,071
S31	10.60	99.6	55.4	7.19	10.22	14.34	4.00	10.74	108,812
S32	10.70	104.4	110.7	7.38	9.19	14.98	5.62	15.64	106,505
S33	11.30	103.7	44.5	7.23	10.08	15.44	5.44	14.37	113,363
S35	11.70	101.5	28.3	6.87	8.73	13.06	4.39	13.42	97,335
S36	11.70	100.7	36.0	7.15	9.32	13.51	3.77	11.84	99,853
S37	11.30	97.3	37.5	7.26	9.77	12.90	3.13	9.49	101,819
S38	10.40	100.4	42.9	7.37	11.54	13.94	2.37	5.86	113,947
S40	9.53	96.5	49.4	7.19	10.79	14.59	3.51	9.15	112,184
S43	10.90	105.7	45.5	7.40	10.90	12.81	1.66	4.77	105,829
S44	10.40	100.2	45.7	7.31	10.80	12.81	1.81	5.11	105,135
S46	9.70	97.5	80.8	7.30	10.39	14.97	4.01	11.17	110,713
S48	10.50	101.6	35.6	7.50	11.01	13.03	2.09	5.49	108,037

Table F-3. (continued)

Stream	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Sat)	Specific Conductivity (µS/cm)	pH (pH units)	Water Temperature (°C)[†]				
					Mean Daily Min	Mean Daily Max	Mean Daily Range	Mean Daily CV	ATU
S50	9.30	98.1	74.1	7.49	9.54	15.31	5.46	14.95	108,873
S52	9.28	96.8	62.6	7.04	8.12	17.22	8.62	23.66	108,238
S53	11.90	106.1	90.6	7.36	11.06	14.98	3.61	9.39	114,875
S54	11.90	102.8	94.9	7.54	10.08	15.28	4.98	13.18	111,665
S57	9.84	94.7	56.0	7.46	9.72	13.27	3.44	9.89	101,696
S58	10.70	96.5	85.8	7.89	10.64	13.58	3.13	8.44	109,210
S59	11.20	100.2	86.0	7.85	9.59	13.29	3.53	10.73	101,698
S60	10.00	99.4	36.3	7.11	10.45	13.77	3.14	8.81	107,859
S62	10.30	110.3	73.0	7.32	9.98	16.15	5.99	15.14	113,808
S63	10.70	99.9	45.3	7.19	10.52	12.78	1.58	4.63	102,082
S64	11.80	106.0	92.3	7.32	10.37	15.29	4.91	12.74	114,213
S65	9.79	92.6	30.9	6.60	9.95	13.39	3.54	10.09	104,343
S66	10.30	97.2	35.1	7.18	9.72	13.64	3.49	10.53	102,417
S67	11.90	102.8	38.4	7.12	9.88	13.22	3.36	9.98	103,738
S70	10.30	105.0	38.4	7.36	9.17	13.29	3.74	12.02	98,672

[†] CV = coefficient of variation, ATU = accumulated thermal units

Table F-4. Occupancy covariates for each site (stream).

Stream	Discharge (m^3/s)	Mean Depth (m)	Mean Velocity (m)	Instream Vegetation (%)	Wetted Width (m)	Mean # of Channels	Slope (%)	Overhanging Vegetation (%)	Undercut Banks (%)	Upland Land Class (%)	Upstream Lake Area (km^2)	Substrate (%)†					
												BO	CO	GR	SA	FI	OG
S02	0.328	0.323	0.041	0	60.2	1.0	1.4	0	0	87.0	3.728	##	0	0	0	0	0
S03	0.045	0.168	0.215	5.2	3.338	3.2	2.0	1	0	0.1	0.206	34	4	6	7	0	49
S04	1.128	0.305	0.454	30	19.968	2.4	2.4	0	0	8.9	3.704	24	25	17	8	0	26
S05	1.157	0.356	0.357	22.2	21.656	1.0	2.0	5	0	8.7	3.768	84	6	0	0	0	10
S06	0.221	0.103	0.183	0.2	10.128	4.2	6.1	3	0	63.3	1.169	95	5	0	0	0	0
S07	0.207	0.144	0.431	5	10.508	5.2	3.9	5	0	5.2	1.230	90	10	0	0	0	0
S08	0.601	0.221	0.199	0.2	29.36	1.2	1.8	2	0	80.6	0.723	90	10	0	0	0	0
S10	0.109	0.118	0.475	43	7.168	2.4	6.6	0	0	0.0	0.057	8	1	1	0	0	91
S11	0.396	0.194	0.392	8.4	28.594	3.0	4.9	50	0	7.0	0.760	97	3	0	0	0	0
S12	0.018	0.152	0.136	18	2.796	1.8	1.5	0	0	38.3	0.060	2	7	4	10	0	77
S13	0.272	0.200	0.378	14.4	14.964	3.2	3.0	2	0	15.2	0.383	37	28	3	0	0	32
S14	0.516	0.225	0.487	1.8	7.088	1.0	3.6	7	0	31.7	1.077	91	9	0	0	0	0
S16	0.189	0.190	0.154	9.6	9.276	1.6	1.6	0	0	33.2	1.474	60	32	5	2	1	0
S17	0.035	0.154	0.117	27	5.602	1.0	1.0	0	0	6.3	0.223	2	2	1	1	0	95
S18	0.159	0.207	0.305	2.8	3.182	1.0	1.6	0	1	21.5	2.000	50	34	16	0	0	0
S19	0.159	0.115	0.201	1.6	9.796	1.2	3.7	0	0	4.4	3.196	72	27	1	0	0	0
S21	0.041	0.141	0.135	4	5.504	3.0	1.1	1	1	0.0	0.904	78	20	2	0	0	0
S22	0.037	0.277	0.128	9.2	2.882	1.8	2.4	0	0	3.2	1.162	16	25	19	10	0	30
S24	0.222	0.081	0.116	8.4	29.438	1.0	1.3	0	0	4.2	3.924	32	34	29	4	1	0
S26	0.736	0.148	0.156	2.4	32.368	1.0	2.2	2	0	0.0	8.060	48	44	8	0	0	0
S27	0.895	0.148	0.203	3.6	44.4	1.0	2.1	0	0	9.2	8.350	61	28	11	0	0	0
S29	0.357	0.254	0.398	5.2	8.09	2.8	2.3	9	3	5.4	2.004	31	46	21	0	0	2
S31	0.027	0.207	0.149	5.6	2.174	2.2	1.1	0	3	11.7	0.662	14	24	13	7	0	42
S32	0.016	0.148	0.099	2.6	1.846	1.6	1.1	0	2	38.1	0.185	32	34	20	2	0	12
S33	0.016	0.162	0.191	14.2	0.992	1.4	3.2	57	8	0.0	0.341	34	13	21	8	0	24
S35	0.004	0.085	0.064	18.8	1.052	1.4	5.0	2	0	15.2	0.120	38	25	12	0	0	26
S36	0.545	0.151	0.166	0.8	41.6	1.6	1.4	1	0	13.5	8.032	59	30	9	2	0	0
S37	0.298	0.114	0.190	4.6	22.224	1.0	1.5	0	0	1.3	8.068	29	35	34	2	0	0
S38	0.342	0.200	0.272	12.2	16.12	1.2	1.4	2	0	0.0	4.494	36	31	33	0	0	0
S40	0.109	0.164	0.246	8.4	8.324	2.2	2.0	5	1	24.8	1.181	60	30	9	0	0	1
S43	1.656	0.311	0.580	3	17.008	1.4	2.0	2	0	1.7	29.037	59	25	11	2	0	3
S44	5.041	0.296	0.446	4.8	42	1.0	1.8	3	0	1.3	29.011	60	36	4	0	0	0
S46	0.060	0.257	0.222	7.4	0.932	1.0	1.0	1	0	0.0	1.010	50	24	16	0	0	10
S48	0.177	0.102	0.232	3	13.942	1.0	2.2	0	0	85.3	2.674	81	17	2	0	0	0
S50	0.056	0.176	0.226	8.8	1.978	1.0	4.1	1	0	5.1	0.326	45	40	15	0	0	0
S52	0.004	0.082	0.095	65	0.77	1.0	2.7	0	0	0.0	0.027	0	0	0	0	0	##
S53	0.106	0.172	0.227	23	3.856	2.0	1.8	1	3	0.0	1.475	30	38	21	11	0	0
S54	0.120	0.166	0.310	3.2	3.504	1.0	3.4	2	0	9.0	1.475	67	28	5	0	0	0
S57	0.048	0.078	0.218	1.2	4.442	1.6	5.4	9	0	37.4	0.129	28	33	31	0	0	0
S58	0.056	0.219	0.020	3.8	30.22	1.0	0.7	0	0	5.5	1.452	96	4	0	0	0	0
S59	0.105	0.140	0.115	5.8	19.95	2.6	1.6	1	0	1.1	1.409	81	16	3	0	0	0
S60	0.307	0.208	0.251	6.2	15.128	4.4	2.1	44	0	4.7	3.496	56	27	13	1	0	3
S62	0.005	0.115	0.075	16.4	1.002	1.2	2.5	1	0	17.6	0.010	6	0	0	1	0	93
S63	3.642	0.317	0.241	1.6	79	1.8	1.5	0	0	0.0	28.923	37	35	28	0	0	0
S64	0.061	0.169	0.125	15	10.246	1.8	1.3	1	6	0.0	1.475	22	24	14	3	0	37
S65	0.044	0.130	0.328	5.6	1.658	2.8	4.6	10	0	4.3	0.230	81	2	0	0	0	17
S66	0.323	0.354	0.279	1	4.49	1.0	1.0	8	45	1.3	3.415	14	47	32	2	0	5
S67	0.215	0.160	0.251	4.4	19.82	1.8	3.2	14	0	8.0	8.118	85	8	0	0	0	0
S70	0.733	0.152	0.194	0.2	56.8	1.0	2.1	0	0	0.7	10.980	92	8	0	0	0	0

† BO = boulder, CO = cobble, GR = gravel, SA = sand, FI = fines, and OG = organics