PREDICTING BROOK TROUT DISTRIBUTIONS USING THE AQUATIC ECOSYSTEM CLASSIFICATION FOR ONTARIOS RIVERS AND STREAMS

By

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PREDICTING BROOK TROUT DISTRIBUTIONS USING THE AQUATIC ECOSYSTEM CLASSIFICATION FOR ONTARIOS RIVERS AND STREAMS

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Major Advisor

Second Reader

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ABSTRACT

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Keywords brook trout, habitat, prediction, association, presence, absence

Brook trout are a highly valued aquatic species that are sensitive to changes in their environment. Studies show that optimal brook trout habitats have declined due to anthropogenic effects like forest fragmentation, agricultural use, and road densities. Understanding the distribution of brook trout within streams will help managers and conservationists maintain population status. Several models have been used for predicting the occurrence of brook trout within streams based on specific brook trout needs and landscape impacts. The Aquatic Ecosystem Classification for Ontario's Rivers and Streams was established in 2013 as a tool to classify all streams in Ontario into ecologically homologous units at several spatial scales. Both habitat and AEC class code requirements could be potential management tools in predicting the presence or absence of brook trout. Overall, the habitat variables examined did not show any utility in predicting brook trout presence or absence. The limited difference of presence and absence status within each AEC class codes proved that the AEC does not provide utility in predicting brook trout occurrence within classified streams.

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INTRODUCTION

BROOK TROUT *SALVELINUS FONTINALIS*

Brook trout (*Salvelinus fontinalis*) or "Speckled trout" are a sensitive aquatic species distributed throughout Ontario's lakes, rivers and streams. Brook trout are a prized sport fish and a significant indicator for water quality. The distinct colouration of brook trout aid in identification. They are distinguished by their deep body, large- mouth extension their 'speckled' colouration of white, yellow, and red spots (Hubbs and Lagler 2004). While spawning, males will exhibit an intense orange-red belly with black pigmentation. The pectoral, pelvic and anal fins are orange or reddish in colour with an anterior black bar and white tips. Brook trout have silvery or white bellies, with olive-green or brown backs. The markings and spots are light coloured on a dark background with some spots coloured red and blue. Their elongated body and large head make up a quarter of the body. A rounded snout is present and terminal mouth with maxilla that extend far beyond the posterior margin of the eye (Scott and Crossman 1998). Several forms of brook trout are recognized in Ontario: The Aurora Trout, which lacks the vibrant colouring of traditional brook trout, are native to two large lakes in northeastern Ontario and the coaster brook trout found in nearshore waters of Lake Superior (Holms et al. 2009).

Figure 1. Brook trout *Salvelinus fontinalis* (Walls of the Wild)

RANGE

The western limit of brook trout distributions is found in northern Manitoba. Their range extends eastward throughout Newfoundland and the maritime provinces (Karas 2002). The northern limit of brook trout is in Quebec and stretches southward along the Appalachian Mountains of the United States and into Georgia (Power 1980). Brook trout are distributed across the province of Ontario (Figure 2). They occur west through the Great Lakes-St. Lawrence watershed and north to James Bay and Hudson Bay. In total, there are 4,326 known water bodies in Ontario that contain brook trout; 3047 of these are self-sustaining populations and 1279 are stocked to support artificial fisheries for brook trout (OMNR 2007).

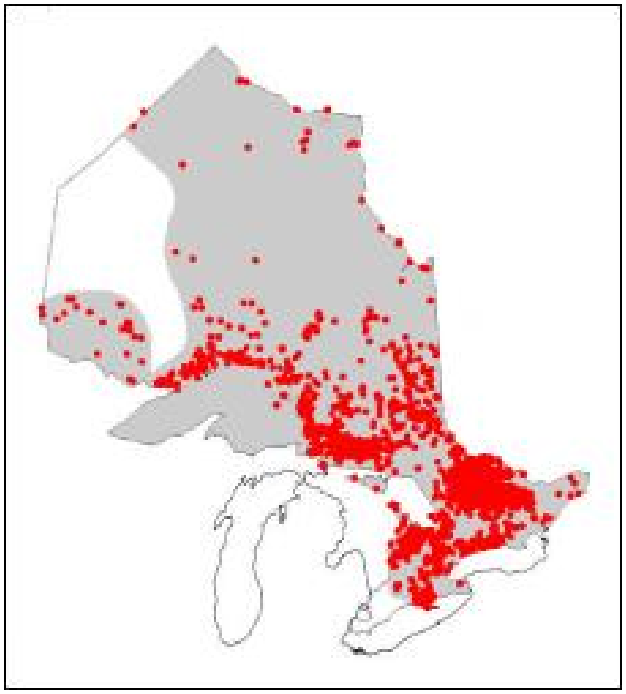

Figure 2. Native range of brook trout in Ontario (Mandrak and Crossman 1992).

HABITAT

An optimal Brook trout habitat includes streams or rivers with clear, cold spring-fed water; a silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool-riffle ration with areas of slow, deep water; well vegetated stream banks; abundant stream cover and relatively stable water flow, temperature regimes, and stream banks (Raleigh 1982). Brook trout are found at various stream depths, widths, and substrates. The main habitat requirement is an abundant supply of clean, cold, well-oxygenated water (Raleigh 1982). Brook trout are highly sensitive to temperature changes in the ecosystem. Temperature is an essential component to brook trout survival across all habitats and life stages (Kanno et al. 2015). Brook trout can be found in water temperatures ranging from 0 to 20°C, but optimal water temperatures for growth and survival range from 11 to 16°C (Raleigh 1982; Gibson 1966). The critical thermal maximum for brook trout is 29.8°C (Feldmuth and Eriksen 1978). Additionally, Kanno et al (2015) found that forested cover is also critical for brook trout. Cover consists of areas of low stream bottom visibility, suitable water depths (>15cm) and low current velocity (<15 cm/s).

Kanno et al (2015) determined environmental factors that influenced brook trout populations in Connecticut headwater streams. Areas of heavily forested catchments with low levels of developed land area were more likely to be occupied by brook trout. Brook trout were associated with areas of groundwater potential, stream slope and stable thermal conditions but not associated with herbaceous plant cover, wetland, and open water area. McKenna and Johnson (2011) confirm that brook trout occurrence and abundance are positively related to forested land and negatively related to impervious cover and agricultural land (Stranko et al. 2008; DeWeber and Wagner 2015).

Stream dwelling adult brook trout prefer moderate flows with mean water velocity across southern Ontario streams supporting brook trout populations ranged from 10.3 to 57.7 cm·sec-1 (Griffith 1972 and Bowlby and Roff 1986). Adult brook trout are opportunistic feeders; in lake habitats they consume a variety of prey including aquatic insects, leeches, crayfish, and zooplankton, and other fish (Kerr 2000).

SPAWNING HABITAT

Brook trout are sexually mature by age 2 or 3, although stream populations are found to mature earlier and at smaller sizes (OMNR 2006). Brook trout spawn in the fall months or when water temperatures are ideal and utilize spawning areas of distinct, discharging groundwater (Curry & Noakes 1995). Spawning starts in early October when the water temperature drops below 10°C (Curry & Noakes 1995). Brook trout select spawning areas where there is sufficient groundwater discharge in both lentic and lotic environments and substrate size between 0.34-8.0 cm (Reiser and Wesche 1980; Curry and Noakes 1994). Groundwater is a critical abiotic factor determining reproductive success in brook trout (Fraser 1985). Groundwater provides abundant oxygen, neutral pH, and thermally stable habitat for egg incubation and protects spawning areas from freezing (Cunjak and Power 1986). Curry and Noakes (1994) concluded that both discharging, and ion-rich water are used by brook trout for spawning in Canadian Shield waters.

During spawning male brook trout situate themselves in riffle areas of a stream in groundwater discharge areas (Holms et al. 2009). Males will become increasingly aggressive and will defend their territory by chasing rivals away while the female creates a redd. Once the pair are pressed against each other, they vibrate, and the eggs and sperm are released. The female will cover the fertilized eggs with gravel to let them develop unattended for two to three months. Eggs hatch when dissolved oxygen (DO) levels are ideally between 4.0 to 8.0mg/L (Fraser 1985). They emerge from the substrate and flow freely in the water while feeding. After emergence, brook trout fry occupy habitats that provide ample cover and food, mostly near their hatching site or nearshore areas (OMNR). Juvenile brook trout feed in shallow water areas and move to deeper areas as they grow. Brook trout range from small-bodied, stream resident lake dwelling populations to anadromous individuals that migrate seasonally between coastal foraging grounds and spawning grounds (Ridgway 2008). Although groundwater is not a primary limiting factor, it can be an important spawning requirement for many populations.

AQUATIC ECOSYSTEM CLASSIFICATION FOR ONTARIO'S RIVERS AND STREAMS

In 2013 an Aquatic Classification for Ontario's Rivers and Streams (AEC) was established by the River and Streams Ecology team, part of MNRF's Aquatic Research and Monitoring Section (ARMS) to summarize ecological differences among streams in Ontario (Jones & Schmidt 2017). Surveys conducted by the Ministry of Natural Resources were used to design and build the spatial data framework to classify all of Ontario's rivers and streams into homogenous units at several hierarchal nested spatial scales (Jones & Schmidt 2017). The AEC has classified ~90% of Ontario's streams correctly. The AEC can be used as a landscape management tool for conservation efforts like monitoring species at risk, invasive species habitat identification, inventories on sensitive aquatic species by providing quantitative assessments of the health of populations, predicting locations of rare species and land use planning for determining unique aquatic features (Jones and Schmidt 2017).

The stream segments are grouped into classes using a multi-tiered binning approach which reduces the complexity of the classification (Jones and Schmidt 2017). The binning considers only the attributes of the segments. Turbidity, base flow index and slope are the considered attributes in defining the segments. The three tiers combine into 16 distinct AEC classes (Table 1). Class codes range from very high ground water potential (VH) with clear (C), fast flowing (F) waters and a BFI greater than 0.65 to streams with very low groundwater potential (VL), turbid (T) and slow moving (S) with a BFI lower than 0.2 (Figure 3) (Jones and Schmidt 2017).

Table 1. Aquatic Ecosystem Classification for Ontario's Rivers and Streams stream class codes with corresponding symbol, baseflow index, channel slope and number of stream segments (Jones and Schmidt 2017).

Symbol	Class Code	Baseflow Index	Channel Slope	Segments (% of Total)
Clear streams*				
	VHCF	≥ 0.65 (Very High)	≥ 0.1% (Fast)	29,224 (8.7%)
	VHCS		< 0.1% (Slow)	11,057 (3.3%)
	HCF	≥ 0.51 AND < 0.65 (High)	≥ 0.1% (Fast)	45,757 (13.7%)
	HCS		< 0.1% (Slow)	16,799 (5.0%)
	MCF	≥ 0.35 AND < 0.51 (Moderate)	≥ 0.1% (Fast)	115,355 (34.4%)
	MCS		< 0.1% (Slow)	66,818 (19.9%)
	LCF	< 0.35 (Low)	≥ 0.1% (Fast)	4,554 (1.4%)
	LCS		< 0.1% (Slow)	1,147 (0.3%)
Turbid streams*				
	HTF	≥ 0.51 (High)	≥ 0.1% (Fast)	2,017 (0.6%)
	MTF	≥ 0.35 AND < 0.51 (Moderate)		8,210 (2.5%)
	LTF	≥ 0.20 AND < 0.35 (Low)		10,701 (3.2%)
	VLTF	< 0.2 (Very Low)		12,576 (3.8%)
	HTS	≥ 0.51 (High)	< 0.1% (Slow)	570 (0.2%)
	MTS	≥ 0.35 AND < 0.51 (Moderate)		2,998 (0.9%)
	LTS	≥ 0.20 AND < 0.35 (Low)		3,706 (1.1%)
	VLTS	< 0.2 (Very Low)		3,530 (1.1%)

*during low flow conditions

Although the AEC has been validated in certain watersheds based on the physical characteristics of streams and rivers, its ability to be used to predict fish distributions has not been tested. The objective of this thesis is to examine the relationship between brook trout distributions and river classes of the AEC to determine if the AEC has the potential to predict the presence or absence of brook trout. It was hypothesized that if the AEC is adequately classifying streams based on habitat features that are important for brook trout, then there will be a significant relationship between AEC classes and the characteristics used to define them, and the presence or absence of brook trout. The AEC index is expected to provide an indication of the type of streams brook trout are distributed in, which can be further used for the application of conservation efforts to protect the species.

LITERATURE REVIEW

IMPACTS OF CLIMATE CHANGE ON BROOK TROUT

Local populations of brook trout in the eastern United States have been declining due to historical and current land use practices and poor management of habitat requirements (Hudy et al. 2008). Water quality, water temperature, nonnative species, fragmented habitat, and destruction have all contributed to reduced brook trout populations (Hudy et al. 2008). Brook trout have been extirpated from 28% of sub-watersheds and greatly reduced (>50% of populations lost) in an additional 35% due to the cumulative impacts of deforestation and poor land management (Hudy et al. 2008; Stranko et al. 2008), acid deposition (Schofield 1976; Haines and Johnson 1982), habitat degradation and fragmentation (Letcher et al. 2007; Whiteley et al. 2013), as well as invasive and introduced aquatic species (Larson and Moore 1985; Wagner et al. 2013). Today, brook trout are undisturbed in less than 5% of their historic US range (Hudy et al. 2008). Changes in brook trout populations are heavily influenced by climatic changes of temperature variation and streamflow influences. Kovach et al (2015) determined that the demography of brook trout age classes is positively associated with streamflow in the summer and fall. Therefore, summer stream flow has a positive influence on brook trout growth and survival slightly more than temperature had an influence on their growth (Kovach et al. 2015).

MODELS PREDICTING BROOK TROUT DISTRIBUTIONS

Due to the sensitivity of brook trout to water temperature changes, the Ontario Ministry of Natural Resources requires timber harvesting companies to leave an undisturbed riparian buffer adjacent to stream containing Brook trout (OMNR 1988). The OMNR has identified numerous Brook trout streams that require riparian protection However, brook trout distribution data in northern Ontario streams is lacking. *Bozek et* *al* (2003) suggest that summer stream temperature is the most important single factor influencing brook trout distributions. Brook trout prefer streams 20°C or lower, so an assessment of thermal characteristics on first and second order streams was completed in northern Ontario within Lake Superior watershed. The effectiveness of five summer indices were determined for designating brook trout streams versus non-brook trout streams. Five thermal indices were calculated based on biweekly measurements of: max. summer temperature; mean max. summer temperature; mean summer temperature; summer temperature stability; and mean sampling temperature. Brook trout were captured in 30 out of 73 streams, and differences in occurrences were correlated with water temperature. All five indices showed cooler temperatures in brook trout streams than non-brook trout streams. Maximum temperature provided the best fit in predicting brook trout presence or absence.

The strong correlation between certain habitat characteristics and observed brook trout distribution, can be used to predict the occurrence or densities of brook trout in areas that have not been surveyed (Steen et al. 2006). Brook trout presence and absence information can be useful in identifying habitat units that are important for the species and that may be vulnerable to alteration and degradation by humans (Steen et al. 2006).

LANDSCAPE SCALE VS SITE SCALE HABITAT REQUIREMENTS

Although large scale population assessments have been completed for aquatic species to identify problems and conservation needs, small scale assessments on self-sustaining Brook trout populations are more effective for restoration initiatives (Hudy et al. 2008). *Hudy et al* (2008) developed a dichotomous key to classify subwatersheds based on the percentage of habitat occupied by brook trout. A model was developed to predict brook trout occurrence in unsurveyed areas and to determine whether cutoffs exist for subwatershed metrics that identify changes in brook trout status. Brook trout populations with intact habitat were found to have forested land usage greater than 68% and road density <1.8km/km^2 (Hudy et al. 2008). Brook trout were found extirpated in areas where deposition (mean of SO_4 and NO_2 deposition kg/ha) was greater than 27kg/ha and agricultural land use was greater than 12% (Hudy et al. 2008). Overall, brook trout are extirpated from 10% of historical occupied watersheds and had a >50% reduction in their habitat in 72% subwatersheds (Hudy et al. 2008).

Kanno et al (2012) used combined air and stream temperature loggers from a total of 36 pairs of streams to characterize stream temperature differences at a local and regional scale. Thermal changes were observed in different stream segments locations but not within the same stream segments. Therefore, it was suggested that regional models of stream temperature would not fully explain the thermal variation within a localized scale and that thermal heterogeneity existed at a local scale.

STREAM AND HABITAT SUITABILITY INDEX:

In 2007 it was determined that, Mid-Atlantic brook trout populations needed to be assessed in order to determine watershed suitability for species protection and conservation efforts (Williams et al. 2007). The Eastern Brook Trout Venture (EBTJV) and Trout Unlimited (TU) used a “Conservation Success Index” developed by Williams et al. (2007) to analyze the status of native salmonid populations. The index uses a multimetric rating system that facilitates protection, restoration, reintroduction, and monitoring efforts which can be used by conservation managers. The key metrics used in the index were: distance from sample site to the nearest road; % agriculture land cover in the watershed; water temperature; riffle quality and dissolved oxygen. ‘Good’ brook trout streams were found in streams with less agriculture use, more dissolved oxygen, cooler temperatures, and further distances from roads (Williams et al. 2007). Three sample streams were used as an example to show that the Brook trout index score (BKTI) is obtained by averaging all individual unitless metric scores. Comparing a standard (best value) scores of the 5 metrics (DO, distance, riffle/run, water temp, %ag) to the BKTI gives an indication of which stream is a greater candidate for stream restoration. Therefore, a stream with a higher Brook trout suitability index will be more of a concern for conservation managers and determining which metric is lacking in suitability can provide information on how to restore and monitor brook trout populations (Sklarew 2012).

MATERIALS AND METHODS

Information on brook trout distributions in Northwestern Ontario has been collected by the Ministry of Natural Resources and Forestry (MNRF) since 1997 (OMNR 2017). Data was obtained for 348 sites across north eastern and western parts of Ontario in Lake Superior tributaries which were sampled for brook trout presence or absence using back pack electrofishing methods (Figure 3). Brook trout counts were recorded as a catch per unit effort and habitat characteristics such as: temperature, riparian vegetation, velocity, depth, pebble count, woody vegetation, invert count, discharge, habitat, and substrate measurements were collected at most sample sites. For this study I analyzed habitat characteristics that correspond to the AEC variables: GDD, channel slope, BFI along with temperature and watershed area (square kilometers).

Figure 3. MNRF sample sites in northwestern Ontario (Wiebe 2018)

Baseflow index (BFI) is a measure of the amount of groundwater contributing to stream flow (Piggot and Sharpe 2007). Baseflow index is important in defining the hydrology and thermal characteristics of stream. BFI values represent the ratio of groundwater to total stream flow for five classes of quaternary geology including coarse and fine textured sediments, till, shallow bedrock, and organic deposits (Piggot and Sharpe 2007). Turbidity is the clarity or cloudiness of the water which relates to productivity of the stream and invertebrate and fish community characteristics. Channel slope is represented by water velocity in streams. Growing degree days (GDD) were used to approximate regional differences in the potential growth and development of ectotherms during the growing season. Growing degree days are calculated by subtracting the stream temperature from a reference temperature to see seasonal changes (University of Wisconsin 2010).

A binary logistic regression using Statistical Package for the Social Sciences (SPSS) was performed on the habitat variables (slope, BFI, GDD, temperature and watershed area) to examine an association with habitat and brook trout presence and absence. Cox and Snell's R^2 and Nagelkerke's R^2 regression models were performed on the categorical dependent variable (brook trout p/a) to see the proportion of variance in the dependent variable associated with the independent variables (habitat characteristics) (IBM 2018). These models are used to estimate the coefficient of determination. Temperature data was divided into six temperature categories. The ranges were split into 3.9°C intervals to clearly visualize brook trout distributions at different temperatures (Figure 6). Groundwater potential data were split into four categories: very high groundwater potential (VH), high groundwater potential (H), medium groundwater potential (M) and low groundwater potential (L) (Figure 7). Using SPSS, a chi-square test was performed on the AEC class codes to determine the significance of the class code on brook trout presence or absence. Boxplot analyses were performed on the variables temperature and baseflow index.

RESULTS

HABITAT RESULTS

Temperature

Overall, there was very little difference in temperature between streams with brook trout present and absent (Figure 5). Streams where brook trout were absent had a temperature median of 15°C and streams with brook trout present had a median of 17°C. Present stream temperatures contained one outlier whereas absent streams had no outliers. Present streams had a narrower temperature range of 8°C to 25°C compared to absent streams which had a temperature range from 6.5°C to 25°C.

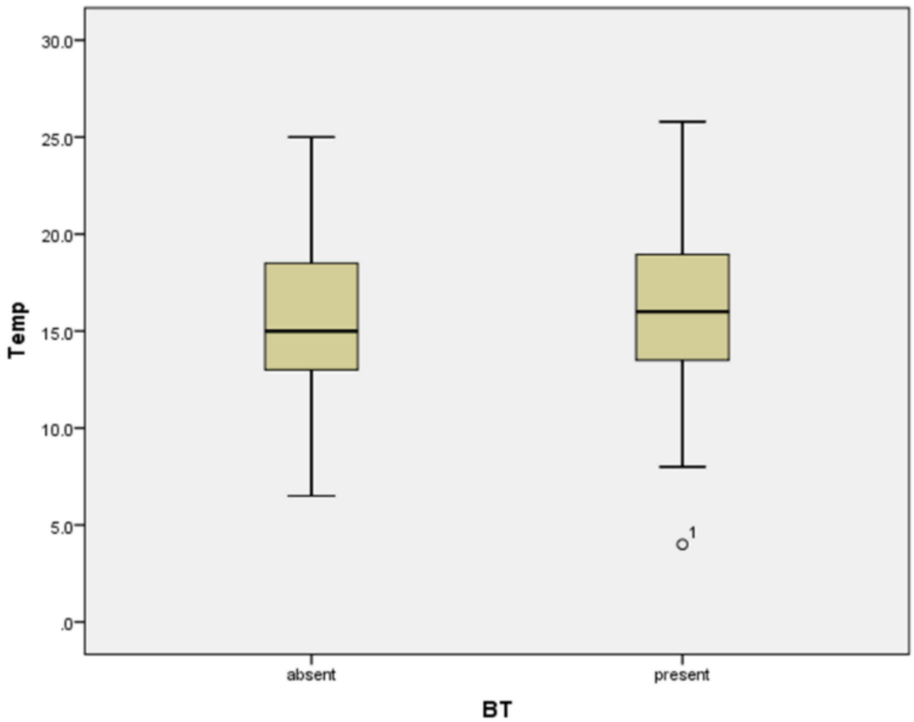

Figure 4. Box plot of stream temperature for streams with brook trout present or absent

Temperature data was divided into six temperature categories. The lowest temperature recorded was 4°C and the highest was 25.8°C (Appendix 1.1.1). The ranges were split into 3.9°C intervals to clearly visualize brook trout distributions at different temperatures (Figure 6).

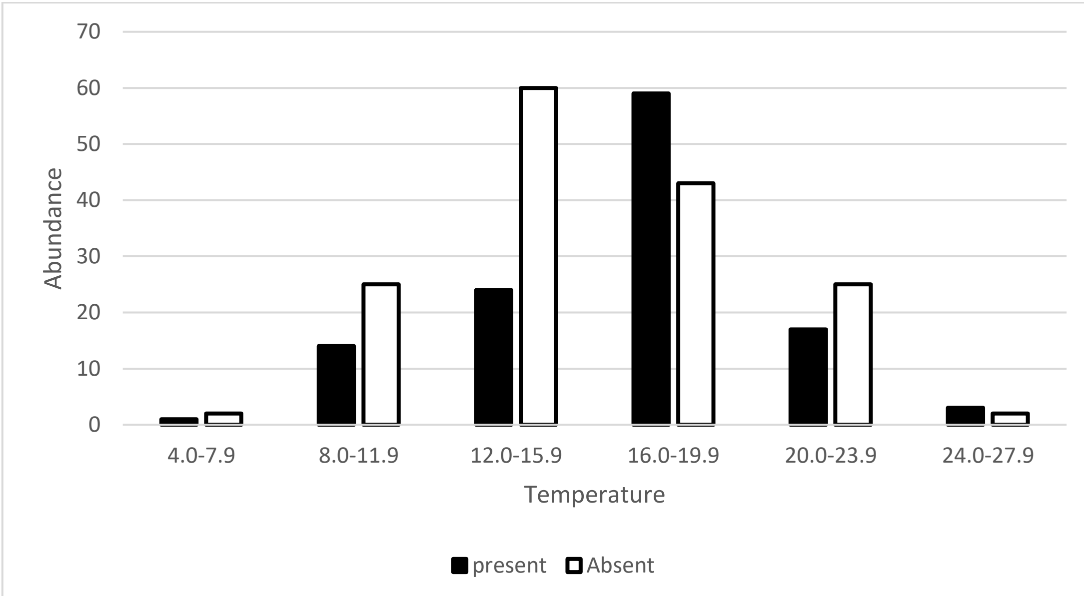

Figure 5. Frequency of present or absent brook trout within temperature ranges

In streams with temperature ranging from 12.0°-15.9°C brook trout absence was more common in 59 of the 102 streams sampled (Appendix 1.1.1). Brook trout were present in a larger proportion of streams with higher temperature ranges of 16.0°-19.9°C with a count of 59 streams in this category having brook trout. The remaining temperature categories had smaller differences in the proportion of streams with brook trout present or absent. The lack of a clear difference in presence and absence temperature categories suggests these categories may be of limited value in predicting brook trout presence or absence.

Groundwater Potential

Most of the streams in the survey fell into the medium groundwater potential category streams (Figure 7). There were 111 absent streams and 94 present streams in medium groundwater potential category (Appendix 1.1.2). Additionally, brook trout were present in a high proportion of the high groundwater potential streams. Sixty-six of the streams had brook trout present and in 47 streams brook were absent. Brook trout were present in a greater proportion of very high and high groundwater potential streams. Medium groundwater potential streams were the most common type in the dataset and absent streams were slightly more common in this category than present streams.

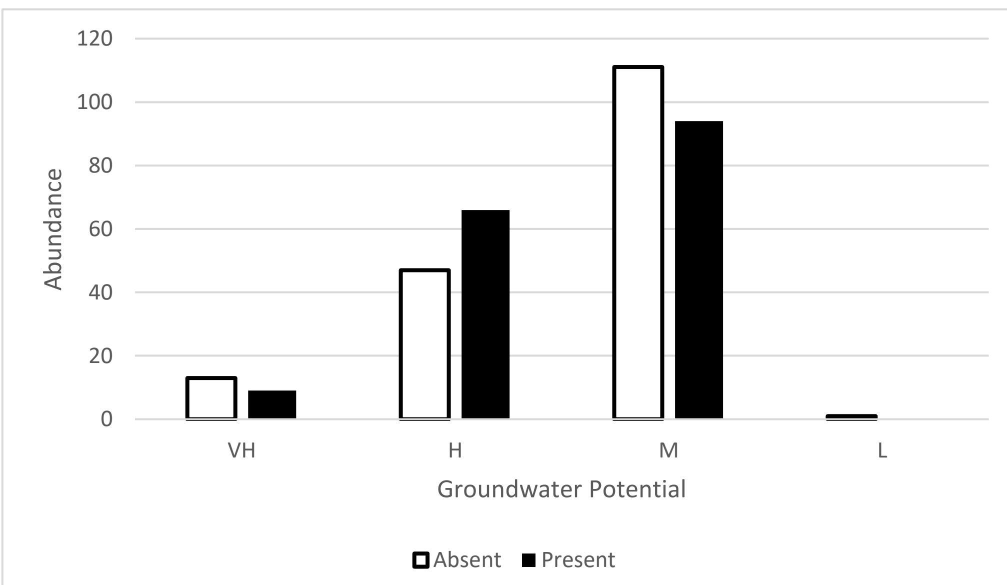

Figure 6. Frequency of present and absent brook trout in different ground water potential levels

Binary Logistic Regression

A binary logistic regression was performed on the habitat variables: baseflow index, slope, growing degree day, watershed area (sqkm) and temperature to test the significance of the variable in predicting brook trout occurrence (Table 2).

Table 2. Results of binary logistic model on brook trout habitat variables

	B	S.E.	Wald	df	**Sig.**	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
BFI	1.427	1.39	1.055	1	**0.304**	4.168	0.273	63.531
Slope	0.102	0.109	0.877	1	**0.349**	1.108	0.894	1.372
GDD	-0.004	0.004	1.094	1	**0.296**	0.996	0.989	1.003
Watershed_sqkm	0.013	0.006	4.952	1	**0.026**	1.014	1.002	1.026
Temp	-0.005	0.036	0.018	1	**0.893**	0.995	0.927	1.069
Constant	3.291	4.216	0.61	1	**0.435**	26.881		

Watershed area (sqkm) is the only variable that contributed significantly to the predictive model indicating brook trout were more likely to be present in larger watersheds (p=0.026.) (Table 2). The other habitat variables did not contribute significantly to the model.

Table 3. Classification results of brook trout presence or absence models

		Predicted		
		BT		Percentage Correct
Observed		0	1	
BT	0	115	36	76.2
	1	83	65	43.9
Overall Percentage				**60.2**

The classification results are shown in Table 3. Overall, the model correctly classified 60% of all the streams. For streams with brook trout absent, the model correctly classified 76% of the cases; for present streams, the model only classified 44% of the cases correctly.

The explained variation in the dependent variable (brook trout p/a) based on this model ranges from 3.5% to 4.6% based on the Cox & Snell R square model and the Nagelkerke R square model (Table 4). A low r square value suggests this model does not explain variance in the dependent variable and is of limited use for classifying brook trout streams.

Table 4. Results of Cox & Snell R square and Nagelkerke R square.

	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
	403.922a	0.035	0.046

a Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

AEC RESULTS

The number of streams with brook trout present or absent were enumerated within each Aquatic Ecosystem Classification for Ontario's Rivers and Streams class code (Figure 8). Brook trout were present in a higher proportion (65 of 112) of the high groundwater potential streams which are predicted to have clear and fast-moving water (HCF) (Appendix 2.1). In the medium groundwater potential streams (MCF), predicted to also have clear and fasting moving water 93 of 198 streams had brook trout present while 105 MCF streams did not contain brook trout (Appendix 2.1).

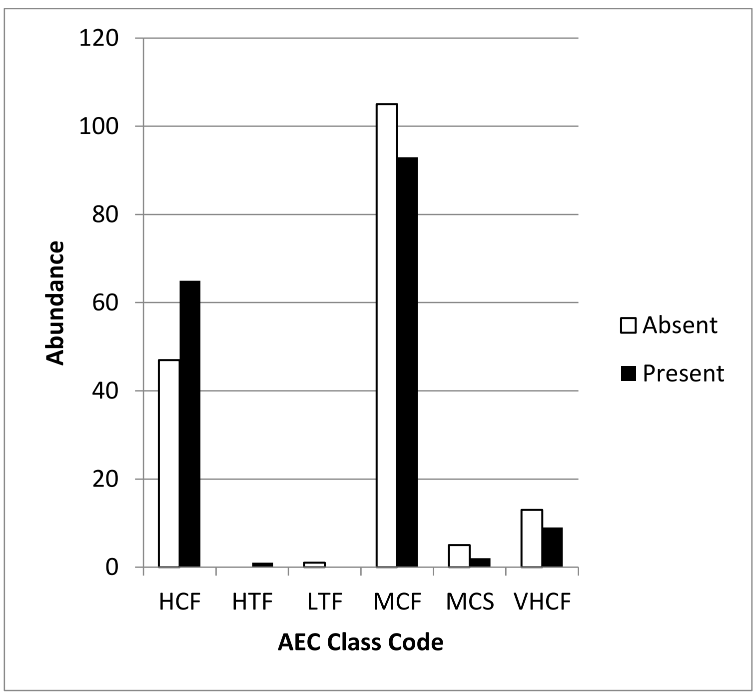

Figure 7. Presence or absence of brook trout in AEC stream classifications

Brook trout most commonly occurred in high groundwater potential streams that are clear and fast flowing (HCF). In all other categories absent streams were more common than present streams. The percent of present or absent brook trout within the four AEC class codes was calculated to evaluate brook trout stream preference (Figure 9). The limited difference of presence and absence status within each AEC class codes emphasizes that the AEC does not provide utility in predicting brook trout occurrence within classified streams.

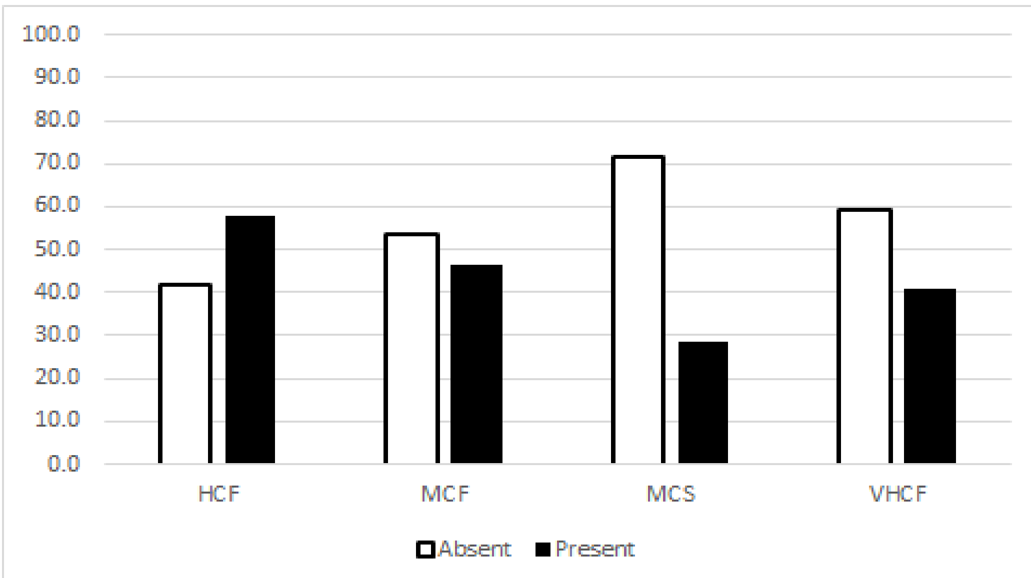

Figure 8. Percent (%) of brook trout present/absent within each AEC class code

There was no statistically significant difference in the proportion of streams with brook trout present or absent within the AEC class code based on a chi-square test (Table 5). The strength of association between presence or absence within AEC class was very weak and not significant based on Phi and Cramer's V tests of the strength of the association (Table 6).

Table 5. Chi-Square test result for AEC significance in predicting brook trout distributions

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	5.870[a]	3	.118
Likelihood Ratio	5.929	3	.115
N of Valid Cases	339		

Table 6. Phi and Cramer's V test of the strength of the association

		Value	Approximate Significance
Nominal by Nominal	Phi	.132	.118
	Cramer's V	.132	.118
	Contingency Coefficient	.130	.118
N of Valid Cases		339	

DISCUSSION

HABITAT CHARACTERISTICS

Of the habitat characteristics analyzed (baseflow index, slope, growing degree days, watershed area and temperature) only watershed area had a slight positive effect on brook trout probability ($p=0.026$) , which suggests that brook trout were more likely to be present in larger watersheds (Table 2). Overall, the logistic regression model was not significant and correctly classified only 60% of the streams (Table 3). A low regression value, no significance and poor classification suggests that the model does not have any utility in predicting brook trout presence or absence.

Brook trout were found in streams with water temperatures between 8°-25.8° C with a high proportion of present streams in the temperature range of 16°-19.9°C (Appendix 1.1.1). This range of stream temperatures is ideal for brook trout (Raleigh 1982). However, there were also a larger number of absent streams with a water temperature ranging from 12°-15.9°C and according to Gibson (1966), 11° to 16°C streams are optimal water temperatures for brook trout growth and survival. Additionally, Kovach et al. (2015) demonstrated that summer stream temperatures and streamflow can additively and interactively influence brook trout survival and growth at different seasons and age classes. Likewise, summer stream temperature provided the best fit in predicting brook trout presence or absence in northern Ontario (Bozek et al. 2003). However, there is limited correlation with my findings since the proportion of streams with brook trout presence and absence was similar for all temperature ranges and streamflow was not assessed.

The habitat variables assessed in this study had no significant ability in predicting the presence or absence of brook trout. However, other habitat variables not examined in this study may have more power in predicting brook trout occurrence if they are more closely correlated to brook trout distributions and not stream characteristics. Sklarew (2012) determined that the most significant variables in predicting brook trout are dissolved oxygen, distance from sample site to the nearest road, riffle quality, water temperature and % agricultural land cover in the watershed. These variables are significant in determining intact brook trout habitats since brook trout are found extirpated in areas where agricultural uses were >12% and depositions of NO_2 and SO_4 are >27 kg/ha. Intact brook trout habitat has forested land cover >68% and road density <1.8 km/km^2 (Sklarew 2012). To predict presence or absence of a sensitive aquatic species like brook trout, more detailed information on their specific habitat needs should be included when developing a predictive model.

AEC CLASS CODES

The Aquatic Ecosystem Classification for Ontario's Rivers and Streams did not accurately predict the presence or absence of brook trout within the AEC class codes. A broad-scale predictive tool, like the AEC, could not be applied for predicting presence or absence of brook trout. The frequency of brook trout present or absence counts did not differ among AEC class codes, making management or conservation difficult. Brook trout counts were highest in medium and high groundwater potential streams (Figure 9). Minimal counts were recorded in very high ground water potential streams which could be due to sampling effort. Brook trout are associated with groundwater discharge sites for spawning (Curry & Noakes 1995). Present and absent samples were recorded between June-August, a few months before spawning season. It could be inferred that groundwater may be a limiting factor in brook trout presence or absence if not sampled in the appropriate season.

Brook trout are expected to be found in small to medium-sized streams with plenty of groundwater flow, which provides cold water and a stable environment (Kanno et al. 2015). Although brook trout presence was more common than absence in the HCF class, other classes such as MCF, which are also predicted to have groundwater potential streams and are clear and fast flowing, did not differ significantly in the proportion of present or absent streams. The utility of the AEC to predict presence or absence may be limited by the lack of variation in classes represented in this study. The vast majority of streams in the study fell into MCF and HCF with very few streams in the classes that may also provide ideal brook trout habitat (e.g. VHCF) and classes where brook trout are not expected (e.g. LTS which are warmer, turbid and slow moving streams). Although the study was not designed to represent all AEC classes, the overrepresentation of MCF is quite likely since a high proportion of stream segments in Ontario are classified as MCF (34.3%) (Table 1). In contrast, preferred brook trout streams like VHCF or HCF make up only 8.7% and 3.3% of streams in Ontario, respectively (Jones and Schmidt 2017) (Table 1).

Brook trout's sensitivity to stream changes make it difficult to predict their occurrence, especially when general stream attributes are assessed instead of species specific habitat needs. At the spatial scale of my study, the Aquatic Ecosystem Classification for Ontario's Rivers and Streams and the types of variables used to construct it, do not appear to be associated with brook trout presence or absence. The AEC is a tool intended to broadly classify the diversity of river and stream types in Ontario and does not account for local scale features like substrate, structure, or cover which may have strong influence on the distribution of aquatic species. There is limited variability in the AEC classes represented in the study, which in turn limits the range of variability in stream features across northern Ontario. The lack of codes does not represent the wide range of variability within streams and the aquatic species that inhabit them.

While the AEC may be useful for classifying streams and rivers at a provincial scale, it does not appear to be useful in predicting brook trout presence or absence at the small scale examined (which is a relatively small and homogenous region of northwestern Ontario). Future studies should focus on increased sampling efforts in LTF and HTF AEC stream types where information was limited. It could be that they are important habitat but are relatively scarce and therefore have not been well-sampled.

The AEC may be used a predictive tool in areas where there is consistent and complete stream data that corresponds to the AEC classification codes. The AEC could act as a good starting tool or a quick tool is determining which species are present within a stream. The presence and absence of brook trout influences several natural resources management decisions, such as: road construction, location and timing and riparian buffer widths, therefore a more accurate model is required.

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APPENDICES

APPENDIX I

1.1 Habitat Variables

1.1.1 Temperature

Table 7. The abundance of brook trout presence or absence within temperature ranges

Temperature	Present	Absent
4.0-7.9	1	2
8.0-11.9	14	25
12.0-15.9	24	60
16.0-19.9	59	43
20.0-23.9	17	25
24.0-27.9	3	2

1.1.2 Groundwater Potential

Table 8. Counts of present and absent brook trout within different groundwater potential levels

	Absent	Present	Grand Total
VH	13	9	22
H	47	66	113
M	111	94	205
L	1		1
Grand Total	172	169	341

APPENDIX II

2.1 AEC Variables

Table 9. Brook trout presence or absence counts within AEC stream class codes

	BT	
Habitat Class	Present	Absent
MCF	92	105
HCF	65	47
VHCF	9	13
MCS	2	5
LTF		1
HTF	1	
Total	169	171

2.2 AEC: Chi Square

Table 10. Brook trout p/a percentage within each AEC class code

BT * ClassCode Crosstabulation

			ClassCode				
			HCF	MCF	MCS	VHCF	Total
BT	Absent	Count	47	106	5	13	171
		Expected Count	56.5	99.9	3.5	11.1	171.0
		% within BT	27.5%	62.0%	2.9%	7.6%	100.0%
		% within ClassCode	42.0%	53.5%	71.4%	59.1%	50.4%
		% of Total	13.9%	31.3%	1.5%	3.8%	50.4%
	Present	Count	65	92	2	9	168
		Expected Count	55.5	98.1	3.5	10.9	168.0
		% within BT	38.7%	54.8%	1.2%	5.4%	100.0%
		% within ClassCode	58.0%	46.5%	28.6%	40.9%	49.6%
		% of Total	19.2%	27.1%	0.6%	2.7%	49.6%
Total		Count	112	198	7	22	339
		Expected Count	112.0	198.0	7.0	22.0	339.0
		% within BT	33.0%	58.4%	2.1%	6.5%	100.0%
		% within ClassCode	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	33.0%	58.4%	2.1%	6.5%	100.0%

This shows that brook trout presence and absence counts are highest in streams that are MCF.

Table 11. Chi -square test results

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	5.870[a]	3	.118
Likelihood Ratio	5.929	3	.115
N of Valid Cases	339		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.47.