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Biological Risk Assessment for Northern Pike (*Esox lucius*), Pumpkinseed (*Lepomis gibbosus*), and Walleye (*Sander vitreus*) in British Columbia

Évaluation du risque biologique posé par le grand brochet (*Esox lucius*), le crapet-soleil (*Lepomis gibbosus*) et le doré jaune (*Sander vitreus*) en Colombie-Britannique

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ABSTRACT

We conducted a qualitative biological risk assessment for three invasive freshwater fish species, the northern pike (*Esox lucius*), pumpkinseed (*Lepomis gibbosus*), and walleye (*Sander vitreus*) for British Columbia. All three species are native to North America, and pike and walleye are native to northeastern BC. All three species are present in southern BC through a combination of introductions and spread from introduced populations in the United States.

The northern pike currently is found in only a few locations in the Columbia basin. There are many documented cases of it causing extensive impacts to fish fauna through predation when introduced; those impacts are most severe in small lakes and on species found in the littoral. The pumpkinseed is found in many locations in southern BC; its expansion into central and northern BC is likely limited by its preference for warmer water temperatures. Pumpkinseed can be considered a nuisance species; it is not normally piscivorous, but it can reach high densities and be a competitor to native fish and impact benthic communities. Walleye have reached BC as migrants in the Columbia River system from introduced populations in Washington State. Walleye have been documented to prey on salmonids and other fish and may decrease the productivity of native populations.

Consequently, all three species are considered to present high risks to native biota if they spread further in BC. Little is known about the impacts of parasites that introduced fish may bring with them.

RÉSUMÉ

Nous avons procédé à une évaluation qualitative du risque biologique posé par trois espèces de poissons d'eau douce envahissantes, à savoir le grand brochet (*Esox lucius*), le crapet-soleil (*Lepomis gibbosus*) et le doré jaune (*Sander vitreus*) en Colombie-Britannique. Les trois espèces sont indigènes en Amérique du Nord, le brochet et le doré jaune sont indigènes dans le nord-est de la C.-B. Les trois espèces sont présentes dans le sud de la C.-B. par le biais de l'effet combiné d'introductions et de propagations de populations introduites aux États-Unis.

On ne trouve actuellement le grand brochet qu'à quelques endroits dans le bassin hydrographique du fleuve Columbia. On relève plusieurs cas documentés d'impacts importants sur l'ichtyofaune en raison de la prédation par cette espèce lorsqu'elle est introduite; ces impacts sont plus importants dans les petits lacs et sur les espèces du littoral. On rencontre le crapet-soleil à plusieurs endroits dans le sud de la C.-B.; sa propagation au centre et au nord de la C.-B. est vraisemblablement limitée par sa préférence pour des eaux plus chaudes. Le crapet-soleil peut être considéré comme une espèce nuisible; dans la plupart des cas, il n'est pas piscivore, mais il peut atteindre de hautes densités et être un compétiteur des espèces indigènes et causer un impact sur les communautés benthiques. Le doré jaune, qui a migré en C.-B. par le réseau hydrographique du fleuve Columbia, provient de populations introduites dans l'État de Washington. On sait que le doré jaune exerce une prédation sur les salmonidés et d'autres poissons, ce qui peut causer le déclin de la productivité des populations indigènes.

En conséquence, ces trois espèces présentent un risque élevé pour le biote indigène si elles poursuivent leur propagation en C.-B. Peu d'informations sont disponibles à propos des impacts causés par les parasites que les espèces introduites peuvent apporter avec elles.

1. INTRODUCTION

The establishment of populations of non-native aquatic species can have very deleterious impacts on native fishes and other components of aquatic ecosystems. Although most non-native species are benign (Moyle and Light 1996; Rahel 2002), those that do have impacts can create significant challenges for resource managers. These impacts include severe reductions or extirpations of native species (Dextrase and Mandrak 2006), reductions in the abundance or productivity of sport, commercial, or culturally important species and habitat alterations (Rahel 2002). Consequently invasive non-native species have been considered a threat to aquatic biodiversity that may rival habitat alteration and destruction (Light and Marchetti 2007).

While some of the more spectacular impacts of invaders in North America are the result of recent intercontinental introductions (e.g., zebra mussel, *Dreissena polymorpha*, round goby *Neogobius melanostomus*, Asian carp, *Hypopthalmichthys spp*.), there has been a much longer history of movements of fish species within the continent. These introductions have expanded the range of many species and contributed to a trend of homogenization of fish fauna in both the United States and Canada (Taylor 2004; Rahel 2007). Beginning in the mid 1800s fish were transported by train from east to west in the US and introduced to various waterbodies in the western States to satisfy demands by European settlers for fish that they had become familiar with in the eastern and Midwest regions. Additionally, water development projects in the west created reservoirs that were stocked with so-called "warmwater" fish such as bass (*Micropterus spp.*) to provide fishing opportunities. As a result the western states have the highest proportion of non-native species (exceeding 50% in some cases) compared to eastern regions (Rahel 2000). Deliberate fish movements westward have not been as actively pursued in Canada and the pattern of homogenization is less pronounced (Taylor 2004). Eastward introductions have usually involved salmonids (e.g., rainbow trout, *Oncorhynchus mykiss*) to diversify recreational fishing (Rahel 2000).

Enthusiasm of government agencies for stocking non-native fish species in western North American continued through the 1980s and contributed significantly to the spread of species such as the pikes (*Esox spp*.), walleye (*Sander vitreus*) and yellow perch (*Perca flavescens*) and various basses and other panfish (centrarchidae). The management of these introductions (largely to provide quality fisheries) has proven challenging and has lead to additional introductions, either of predators to control proliferate and stunted populations, or prey species to provide forage. These issues, as well as a greater understanding of and concern about the impacts of introduced species on native biota have lead to a more conservative approach in the past 20 years (Rahel 2002).

In British Columbia most agency-sponsored introductions have been salmonids for the purpose of recreation and commercial fishing. Brook char and brown trout have been introduced from outside of BC, and all *Oncorhynchus* spp*.* have been introduced or stocked in lakes and rivers to increase production. Authorized introductions of the warm-water species (prior to 1940) were very limited but resulted in the initial introductions of species such as smallmouth bass (*M. dolomieu*) and pumpkinseed (*Lepomis gibbosus*) to BC (Hatfield and Pollard 2006).

While agency-lead stocking programs have taken a more conservative approach in recent years there has been in increase in the spread of a suite of non-native species in western North America through unauthorized introductions, presumably by anglers attempting to create or enhance sport fisheries. Often the species have spread beyond the initial point of introduction and have caused management agencies to put considerable effort into control measures

(McMahon and Bennett 1996). Most notable are the northern pike (*E. lucius*) of Davis Lake, California, where agencies have expended upwards of $10M in repeated attempts to eradicate this invader (CDFG 2000).

This document considers the risk to aquatic communities in British Columbia posed by the potential expansion in the range of the northern pike (*Esox lucius*), pumkinseed (*Lepomis gibbosus*), and walleye (*Sander vitreus*). Pike and walleye are native to northeastern BC, but have been introduced into southern BC, largely by spread from introduced populations in the Pacific Northwest of the United States. Pumpkinseed were introduced into southern BC over 50 years ago.

1.1 The risk assessment process.

The format of the risk assessment for British Columbia follows the "National guidelines for assessing the biological risk of aquatic invasive species in Canada" (Mandrak and Cudmore 2006). This is a qualitative rating process that serves to summarize existing information and identify the relative risks posed by yellow perch. A biological synopses for these species have been commissioned (Harvey 2008; Hartman 2008; Jordan et al. 2008), that provide information of the species natural history, distribution, and documented instances where they have been shown to impact aquatic communities as an invasive species. A supporting document (Runciman and Leaf 2008) details known occurrences of each species in BC.

Risk ratings for each species were determined by a workshop convened March 4-6, 2008 in Richmond, BC, that involved the authors, staff from the DFO Centre for Expertise for Aquatic Risk Assessment, and local and national experts on this species.

This risk assessment is conducted at a relatively broad scale and is not intended to provide detailed information or advice for specific waterbodies or on impacts to individual populations or species. More detailed assessments are required in these cases; recent examples are available for northern pike in Alaska (SANPCC 2006) and California (CDFG 2000).

To accommodate regional differences in BC, we divided the province into 8 regions roughly patterned on those used by Taylor (2004; Figure 1.1). The regions take into account major drainage basins and differences in human population distribution. Statistics for the regions are provided in Table 1.1.

Table 1.1. The number of lakes and reservoirs and the size of each analysis region.

Region	Region Code	Number of lakes and reservoirs	Area (land) of the region (km^2)
Arctic drainage	AR	19 518	421 370
North Coast	NC	10 070	235 925
Central Coast	CC	9 147	85 535
Upper Fraser	UF	14 870	158 476
Lower Mainland	LM	1 631	38 753
Thompson	TH	5 443	55 777
Columbia	CO	3 796	136 943
Vancouver Island	VI	2 654	34 883

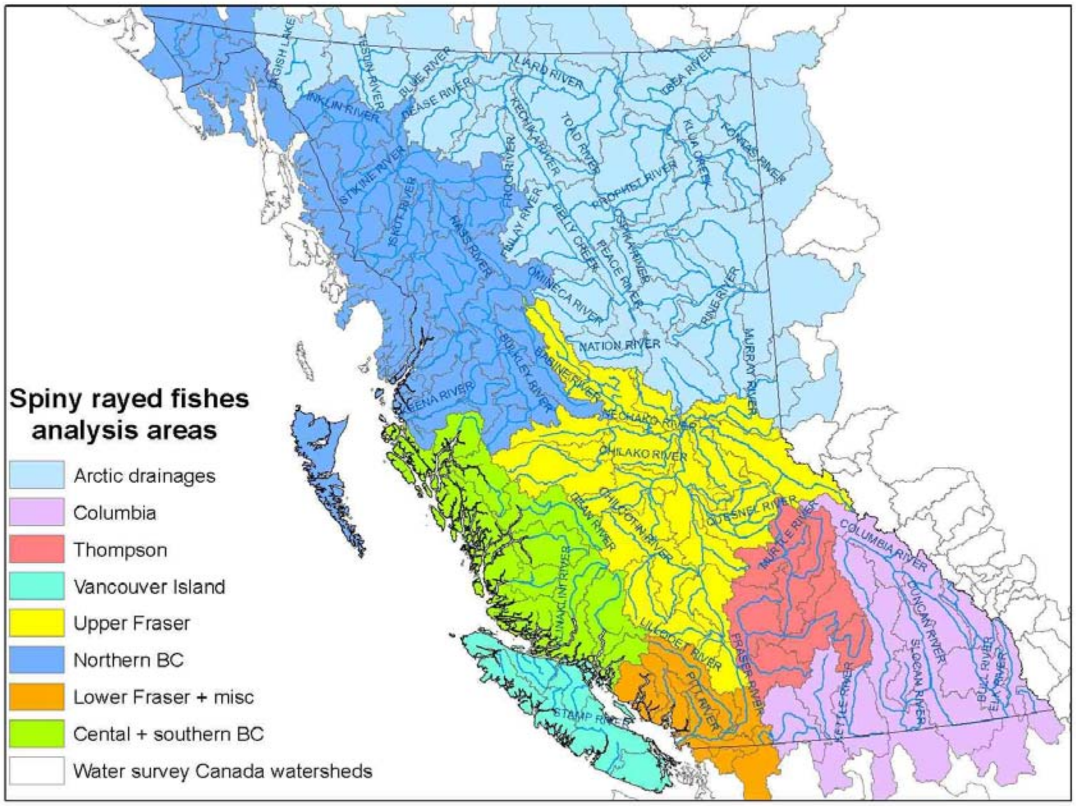


Figure 1.1. The eight analysis regions for use in the risk assessment process. The Arctic region includes headwater tributaries of both the Mackenzie and Yukon Rivers. The lower mainland region includes small transboundary basins and the Sunshine Coast/Whistler area.

1.2 Assessing risk

The National Guidelines breaks the risk assessment into two steps: (1) estimation of the probability of establishment (defined as the sequence of arrival, survival, reproduction and spread), and (2) the determination of impact once introduced, in terms of its ecological and genetic impact on existing aquatic communities. These two analysis steps are conducted both for the species of interest, and are repeated for any pathogens or “fellow travelers” that may be associated with the invader. The evaluation of the probability of establishment or the consequences of introduction is based on qualitative constructed scales with a corresponding assessment of uncertainty.

The first component of the establishment process is the probability of arrival. If the species was already present within a region a risk rating was not needed and an ‘A’ was entered in the tables. Arrival in the region depends on the presence of populations in adjacent regions, the likelihood of spread (especially downstream) from adjacent regions, and the likelihood that the species would be spread by unauthorized introduction (depending on the history of introductions and human population density; Table 1.2).

Table 1.2. Constructed scale to guide the ranking of the probability of arrival of an invasive species into one of the analysis regions.

Element Rank	Descriptor
Very Low	No connected waterways, no nearby donor populations and/or little human influence in the region.
Low	Source populations not close and/or low human density.
Moderate	Some populations in adjacent regions and/or potential for human translocation.
High	Source populations common in adjacent region, recent history of introductions in adjacent regions.
Very High	Almost certain to occur: source populations upstream and likely to spread by natural means and/or a species that is commonly introduced by unauthorized means and has populations in nearby regions.

The second element is the survival and reproduction of the species once introduced. For each species a different habitat modeling technique was used to evaluate the suitability of lakes of the region. Modelling results translated into ranks based on the scheme in Table 1.3. Details of the models are provided in section 2. Although there is a potential for climate change to alter the suitability of habitats in the future it was not considered in this analysis.

Table 1.3. Constructed scale for survival and reproduction based on habitat modeling.

Element Rank	Habitat or environmental score
Very Low	≤ 1
Low	2-10
Moderate	11-50
High	51-80
Very High	>80

The final element of establishment of the species considers the spread of the species within the region once it is introduced. The evaluation is based on the combined effects of natural and human spread. We considered the degree of connectedness of suitable waterways within the region that would allow the species to spread naturally from its point of origin. Also included is the potential for spread by human vectors, most notably through inadvertent or deliberate introductions. The component related to human vectors is based on the human population size and/or the number of visitations of sport fishers to the region. The recent pattern of introductions influences this evaluation (Table 1.4).

Table 1.4. Constructed scale for the probability of spread once introduced into a region.

Element Rank	Descriptor
Very Low	No connected waterways of suitable habitats and little human influence in the region and/or sedentary species.
Low	Waterways not well connected or species unlikely to be introduced by humans.
Moderate	Can spread to adjacent waterways, but species may not be a successful colonizer. Limited interest in introduction of species.
High	Will likely spread to connected waterways and become established and/or species likely to be introduced at a number of locations or a number of times in the region.
Very High	Very well connected waterways and/or species has been noted to spread widely in other regions and/or human population density or visitations of sport fishers very high within the region.

The final element of the establishment rating is an overall consideration of the probability of the fish species, or its pathogens, parasites, or fellow travelers becoming widely established in each region once they have arrived (Table 1.5). This was based on an expert assessment of the probability of survival and reproduction as well as spread, and was guided by the definitions provided in Table 1.5.

Table 1.5. Constructed scale for the widespread establishment of a fish species or its pathogens, parasites, or fellow travelers within each region.

Element Rank	Descriptor
Very Low	Unlikely to become an invasive species in the region.
Low	Species will likely be restricted to isolated waterbodies within the region.
Moderate	Species may become established in a few watersheds within the region.
High	Species likely to become established at multiple locations within the region and concentrated in certain areas.
Very High	Likely to become widespread in the region, occupying many of the suitable lakes and rivers.

The evaluation of the magnitude of consequences considers the risk of the invasive species to Canadian biotic and abiotic resources (Mandrak and Cudmore 2006). The focus in this report is on native BC fishes and other biota, and includes species such as rainbow trout and salmon that may be enhanced (i.e. stocking and hatchery programs) for human use. No weighting or special consideration is given to specific species or populations at this level of review. Table 1.6 contains descriptors we used to guide us in determining the magnitude of the consequences of an introduction of an invasive species in both ecological and genetic terms.

Table 1.6. Constructed scale to guide the evaluation of the magnitude of the ecological or genetic consequences of an invasive fish species, their pathogens, parasites, and fellow travelers in a given water body or area.

Element Rank	Descriptor of impact
Very Low	Species integrates into aquatic community and has no discernable impact on existing biota or genetic exchange with native populations impossible.
Low	Native species are sometimes impacted by predation, competition, disease, or habitat alteration as a result of the invasion or genetic exchange with native populations highly unlikely.
Moderate	A measurable decrease in abundance of native populations is likely to occur in most locations or genetic exchange with native populations may occur in some instances and cause harm.
High	The invasive species becomes a dominant component of the food web and causes significant reductions in existing biota or genetic exchange with native populations likely to occur in some circumstances and cause harm.
Very High	Extirpation of native populations likely. Food webs are highly altered or genetic exchange is likely to be widespread or seriously deleterious.

The ecological impact assessment was done separately for small (<1000 ha) and large water bodies within BC.

Accompanying both the probability of introductions and magnitude of effects tables are assessments of the uncertainty associated with each determination. There are at least two components of uncertainty: the natural biological and ecological variability associated with stochastic events, and the scientific uncertainty resulting from a lack of evidence for a particular species. The uncertainty measure here focuses on scientific understanding (Table 1.7). We have taken an evidenced-based approach and assess risk by reviewing empirical information. Scientific uncertainty is lowest when there are studies on the target species in similar ecosystems, uncertainty is high when analogue species must be used or when impacts must be inferred from dissimilar or distant ecosystems or experiments.

Table 1.7. Constructed scale for the evaluation of uncertainty in the risk assessment ratings.

Rank	Interpretation of uncertainty
Very Low	Demonstrated: outcome known with certainty in BC.
Low	Similar: case studies in similar ecosystems for the target species.
Moderate	Expected: inferred from knowledge of the species in its native range.
High	Plausible: based on ecological principles, life histories, or experiments.
Very High	Unknown: little information to guide assessment.

Finally, the summary ranks for the probability of widespread establishment and the ecological or genetic consequences are combined in the following table to obtain an overall risk rating (Table 1.8). An ellipse was placed on the matrix based on the risk evaluation. The size of the ellipse was adjusted to reflect the uncertainty in the assessment. Separate ellipses were used in cases where there were differences among region.

Table 1.8. Matrix for determining overall risk, where green indicates low risk, yellow indicates moderate risk, and the red region represents the conditions for a high risk designation (from Mandrak and Cudmore 2006).

Ecological or Genetic Consequences						
	Very High	yellow	yellow	red	red	red
	High	yellow	yellow	yellow	red	red
	Medium	green	yellow	yellow	yellow	red
	Low	green	green	yellow	yellow	yellow
	Very Low	green	green	green	yellow	yellow
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

2. HABITAT MODELING

2.1 Northern pike.

We obtained occurrence data for northern pike from the Ontario Habitat Inventory Index which summarizes species occurrence, geographic location, physical habitat, and water chemistry for 7 567 Ontario lakes. The presence of each species was recorded in the same dataset. The Ontario dataset was randomly divided into training and validation datasets (80:20 ratio) with the same large-scale geographic coverage in both datasets.

We obtained data for the occurrences of pike in lakes in British Columbia from Runciman and Leaf (2008). Physical habitat and water chemistry variables in BC were from the British Columbia Ministry of Environment. Mean monthly air temperature data were obtained from the WorldClim database (www.worldclim.org) and provided on a 30 arc seconds or about a 1 km resolution. The mean monthly air temperature data for lakes in Ontario and British Columbia was extracted using ESRI ArcGIS 9.1. Nineteen environmental predictor variables were used in a habitat suitability model for each species: lake perimeter (m), lake surface area (ha), maximum depth (m), elevation (m), surface pH, surface total dissolved solids concentration ($mg \cdot L^{-1}$), Secchi depth (m), and monthly mean air temperatures. Out of the 67 463 lakes and reservoirs in the BC Environment lake database, environmental variables that were the same as the Ontario dataset were available for 1 882 lakes.

Multicollinearity between variables was evaluated using bivariate plots and correlation analyses prior to regression analyses to determine which variables should be retained. Additionally, variables were log transformed as necessary to satisfy the assumption of normality. Variables included in the models were: surface area, maximum depth, perimeter, elevation, Secchi depth, pH, total dissolved solids concentration and mean monthly air temperatures.

Stepwise multiple logistic regression models were constructed for Ontario lakes using the training dataset in SAS statistical software to evaluate the relationship between fish occurrence and physical habitat, water chemistry, and climatic predictor variables. In a logistic regression, response variables are subject to a logit transformation, whereas predictor variables are based on a linear combination using maximum likelihood (Olden and Jackson 2002). Significance values for predictor variables were set at a value of 0.05 to enter and remain in the model.

The logistic regression models were tested on the Ontario validation dataset. We also tested the logistic regression models on the British Columbia occurrence dataset. The use of large independent data sets is necessary in order to evaluate the model and determine its generality, although it has been traditionally rarely used in ecological studies (Pearce and Ferrier 2000; Ozesmi et al. 2006). Without proper validation, these models generally overestimate their predictive capability (Olden et al. 2002).

We applied the logistic regression models to the 1882 lakes with data in British Columbia to identify the potential occurrence northern pike. The proportion of lakes in each watershed (Figure 1.1) was calculated for mapping purposes; watersheds with less than 5 lakes were excluded. The proportion of lakes suitable in each region was also calculated.

2.2. Pumpkinseed.

Habitat suitability or environmental niche modeling for pumpkinseed were not considered to be successful at the peer review meeting. As an alternative, climate as indexed by growing season was used. We used a Natural Resources Canada (NRCan) atlas of growing season (defined as the number of degree-days (DD) >5 °C) for Canada. The natural northern limit of the best pumpkinseed habitat in eastern Canada was observed to be well correlated to the 1750 DD isocline. There were also some populations within the 1500-1750 DD range. Consequently the potential range of pumpkinseed in BC was identified with the 1500 and 1750 DD isoclines. For each analysis region the proportion of the region that was sufficiently warm for pumpkinseed was visually assessed at the peer review meeting, and Table 1.4 was used to rate each region.

2.3 Walleye.

The habitat suitability model did not perform well for walleye, so the potential occurrence in BC was predicted with an environmental niche model. For the development of the model, occurrence points of each species for North America were extracted from FishBase (http://filaman.ifm-geomar.de/search.php). These occurrence points were used for the development of environmental niche models using the Genetic Algorithm for Rule-set Predictions (GARP; Peterson & Vieglais, 2001). The climatic and geographic coverages tested for each species model included frost frequency (days of frost per year), slope, compound topographic index (wetness index based on flow accumulation and slope), mean daily precipitation, river discharge, wet day index (days of precipitation per year), and minimum, mean and maximum annual air temperatures (see Table 2.1 for more details). A GARP simulation using all possible combinations of environmental coverages allowed us to determine the effect of each layer on model accuracy using multiple linear regression analysis. We used the tolerance value to test for multicollinearity between environmental variables (Quinn and Keugh 2002). Model accuracy was determined by the number of presence points (omission errors/ false negatives), and pseudo-absence points (pseudo commission / false positives) correctly predicted by GARP for all permutations of the environmental coverages. Variables positively correlated to omission errors (i.e. increased the number false positives) were rejected. In cases where the relationship between omission errors and an environmental variable was not significant, it was only included in the prediction if it was positively correlated with pseudo commission (Anderson et al. 2003, Drake and Bossenbroek 2004).

Once suitable environmental coverages for each species were determined, models were generated using a maximum of 1 500 iterations and a 0.001 convergence limit following the best subset method (Anderson et al. 2003). This approach uses a <5% limit on the ratio of test data points outside the predicted range (false negatives, omission errors) and a <50% limit for ratio of predicted suitable environment without test data points (false positives, commission errors) (Anderson et al. 2003). Once 100 models fulfilling these criteria were generated, they were converted into a map of percentage environmental suitability (Arcmap 9.1; Drake and Bossenbroek 2004). These percentages were summarized for each analysis region.

Table 2.1 Layers used in the environmental niche model.

Variable	*Grid size*
Ground frost frequency (number of days per year)	0.5˚ x 0.5˚
Maximum temperature (°C)	0.5˚ x 0.5˚
Mean temperature (°C)	0.5˚ x 0.5˚
Minimum temperature (°C)	0.5˚ x 0.5˚
Wet day index (number of days of precipitation per year)	0.5˚ x 0.5˚
Mean daily precipitation (mm)	0.5˚ x 0.5˚
Topographic index (wetness index based on flow accumulation and slope)	1km x 1km
Slope (maximum change in elevation between a cells)	1km x 1km
River Discharge ($km^3 \cdot a^{-1}$)	0.5˚ x 0.5˚

3. NORTHERN PIKE

3.1 Background and Biology.

The northern pike (*Esox lucius*) is the most widely distributed member of the pikes, and is native to northern North America, Europe and Russia (Scott and Crossman 1973). The pike is a large fish, reaching 1 m in length; females are generally larger than males. Pike are distinguished by a large, flattened mouth and posterior insertion of the dorsal and anal fins. Age at maturity is variable, and can range from 3-5 years for females and a year younger for males. Maximum age can be as great as 30 years. Reproduction occurs in the spring (mid-May) when water temperatures are rising. Spawning usually occurs in flooded vegetation of tributary streams; spawning in vegetated lakeshores has also been observed. Fecundity increases with size and can range from 15 000 to 100 000 eggs per female (Scott and Crossman 1973).

Northern pike eggs are adhesive and stick to vegetation; their development is temperature dependent and can range from 5 to 30 days. Newly hatched larvae have an adhesive gland on their heads and attach themselves to vegetation for 10-15 days during the period of yolk absorption (Bry 1996). After this initial period larvae feed on zooplankton for 7-10 days before switching to a fish diet. Juvenile pike grow rapidly, and are often greater than 15 cm TL by the end of their first year. Shallow vegetated areas are the primary habitat for larval and juvenile pike (Bry 1996).

Adult pike are visual ambush predators, and their preferred habitat is shallow beds of aquatic plants, or other forms of cover in relatively still, clear, water. Apart from spawning migrations pike are considered quite sedentary during the growing season, although various short-term movements have been observed (Chapman and MacKay 1984). Their diet generally consists of fish, but also includes invertebrates, birds, mammals and amphibians up to one-half of the pike’s body length. Prey species inhabiting littoral zones are common in the diet, with yellow perch and suckers being prevalent in many areas. Soft bodied fishes such as minnows are generally preferred to species with spines such as centrarchids (Wahl and Stein 1988). Cannibalism does occur and can be an important factor in the population dynamics of this species.

Pike have relatively wide environmental tolerances. The upper thermal limits appear to be in the range of 29-30° C, but temperatures of 20-22°C are optimal for growth and swimming performance (Casselman 1996). Pike move from shallow rearing areas to deeper water when summertime heating causes surface waters to exceed optimal levels. Their presence in polar environments implies that pike can survive long winters and short growing seasons. Pike can survive at oxygen concentrations of <1 mg/L but will move when oxygen levels fall below 4 mg/L. These depressed oxygen levels can occur during the summer in shallow weed beds from respiration associated with decaying plant material. Pike can tolerate wide range of alkalinities, and pike have been found in waters with pH values ranging from 6-9. Northern pike can also tolerate brackish water, up to 10 ppt. Such tolerance has allowed pike to move among tributaries in brackish inlets (Rutz 1996) resulting in the colonization of coastal streams in the Cook Inlet in Alaska.

A large suite of parasites and diseases has been identified in pike. This is probably the result of its wide distribution, diverse dietary habits and the many years this species has been studied (Dick and Choudary 1996). Some of the parasites are generalists; others are specific to Esocidae. Of note is the tapeworm *Diphyllobothrium latum*: this species can infect humans if uncooked flesh is consumed. The cestode *Triaenophorus crassus* infects pike as pike as its definitive host, however salmonids are used as an intermediate host (Rosen and Dick 1984). Bauer and Solomatova (1984) note that salmonid culture in waters where pike are present may be difficult as infections by *Triaenophorus* can render trout unmarketable. Pike are also susceptible to *Viral hemorrhagic septicemia* (Grookock et al. 2007), an emerging disease that is spreading through many species in the Great Lakes region.

Northern pike have expanded from their native range largely via stocking by natural resource agencies, as well as some unauthorized introductions. Although a largely sedentary fish, they do expand their range when conditions permit. Spens et al. (2007) examined pike distributions in Sweden, and concluded that 100% of lakes downstream of source populations had become colonized with pike. Upstream colonization potential was successfully modeled using stream gradient, and predicted that pike colonization would be restricted by the presence of high-gradient barrier reaches.

3.2 Known Distribution.

The native distribution of northern pike in Canada extends from Labrador through Alberta and includes the Yukon, Northwest Territory and southern Nunavut. Pike are not native to Newfoundland or the Maritime Provinces (Scott and Crossman 1973). The native range also includes the Great Lakes states, and the Mississippi basin west to Montana and south to Missouri. Pike have been introduced to many of the Western states, as far as California and Arizona (Moyle 2002). Pike were initially illegally introduced into Idaho and eastern Washington State in the 1970s and now occur in a number of reservoirs and rivers. One river (Spokane River) is a tributary of the Columbia River basin in Washington, and expansion of the species through the Columbia Basin is considered likely in time (Wydoski and Whitney 2003).

In British Columbia pike are native to the lower Peace and Liard Rivers, and the Hay River system of northeastern BC (Figure 3.1). Pike are also found in the Yukon River tributaries along the BC-Yukon border, and in the Taku and Alsek Rivers of northwestern BC. McPhail (2007) suggests the presence of pike in these Pacific drainages is the result of recolonization from Beringia (a glacial refugium). McPhail also noted a failed attempt to introduce pike to the Crooked River of the upper Peace drainage. Northern pike have been introduced into Charlie

Lake near Ft. St. John. They have also recently been observed in Ha Ha Lake and the Kootenay River in southeastern BC (Figure 3.1).

Table 3.1. Counts of waterbodies containing introduced northern pike, by region, in British Columbia, from Runciman and Leaf (2008).

	Region						
	Vancouver Island	Lower Mainland	Fraser	Thompson	Columbia	Arctic	Coast
Confirmed	0	0	0	0	2	1	0
Unconfirmed	0	0	0	0	0	0	0

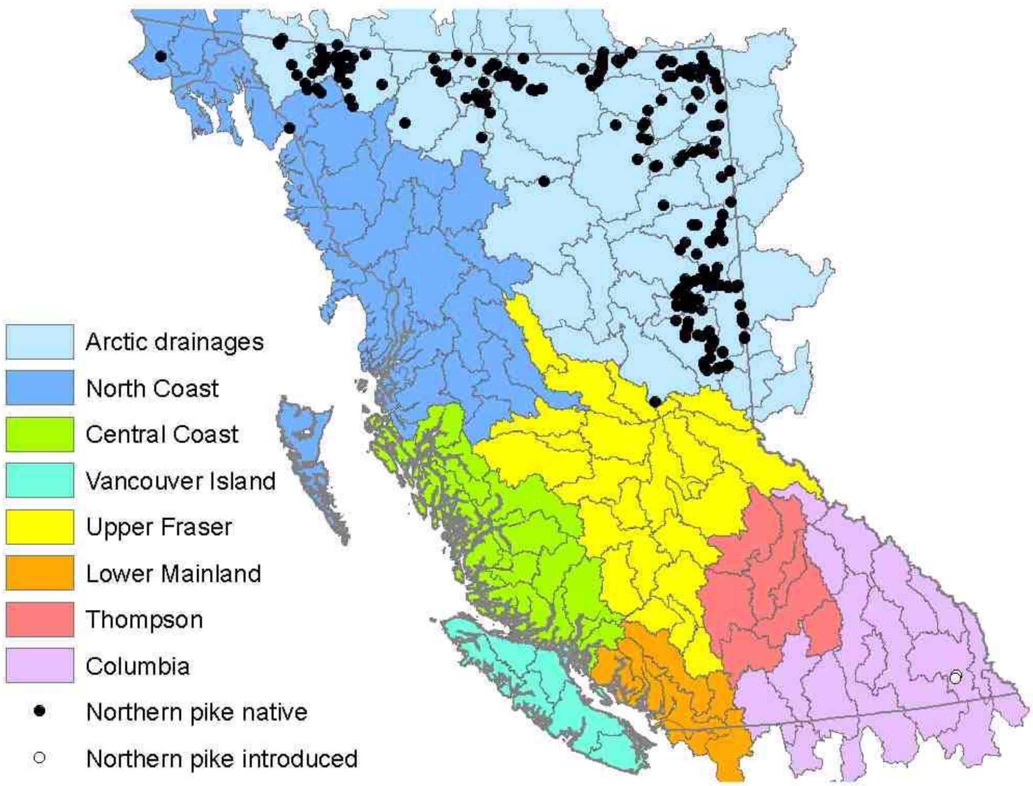


Figure 3.1 Observations of pike in British Columbia, from Runciman and Leaf (2008).

3.3 Potential Distribution.

The northern pike model is based on twelve environmental variables (January air temperature, total dissolved solids concentration, November air temperature, February air temperature, October air temperature, area, March air temperature, maximum depth, September air temperature, December air temperature, Secchi depth), with January air temperature, total dissolved solid concentrations, and November air temperature being the most important variables. The validation based on the BC dataset showed intermediate model performance with only 21 out of 37 lakes with occurrences reports correctly predicted as invaded or established. Unfortunately there was limited environmental data available for most watersheds within the Arctic drainages which form part of this species native range. More lake-specific data for this area would have allowed a more detailed model evaluation. Northern pike is only predicted to be able to persist in a low percentage of lakes across BC, with the highest predictions for the Upper Fraser, North coast and Lower Mainland regions (Table 3.2). The lowest predictions were for the Thompson and the Columbia regions.

Note that these predictions are based on overview-level lake attributes, and do not consider the specific habitat requirements of pike, particularly the presence of shallow vegetated areas and clear water considered critical for pike spawning and rearing (Casselman 1996). Northern pike are unlikely to establish in glacial lakes, those without extensive littoral zones and macrophyte beds, or reservoirs with operating regimes that impact littoral zone productivity. Similarly, pike are not usually found in swift moving rivers.

Table 3.2. Proportion of lakes predicted to be suitable habitats for northern pike in each of the 8 analysis regions (n=1882 lakes).

	Region							
	Vancouver Island	Lower Mainland	Upper Fraser	Thompson	Columbia	Arctic	C. Coast	N. Coast
% Suitable	31	39	45	12	13	33	24	43

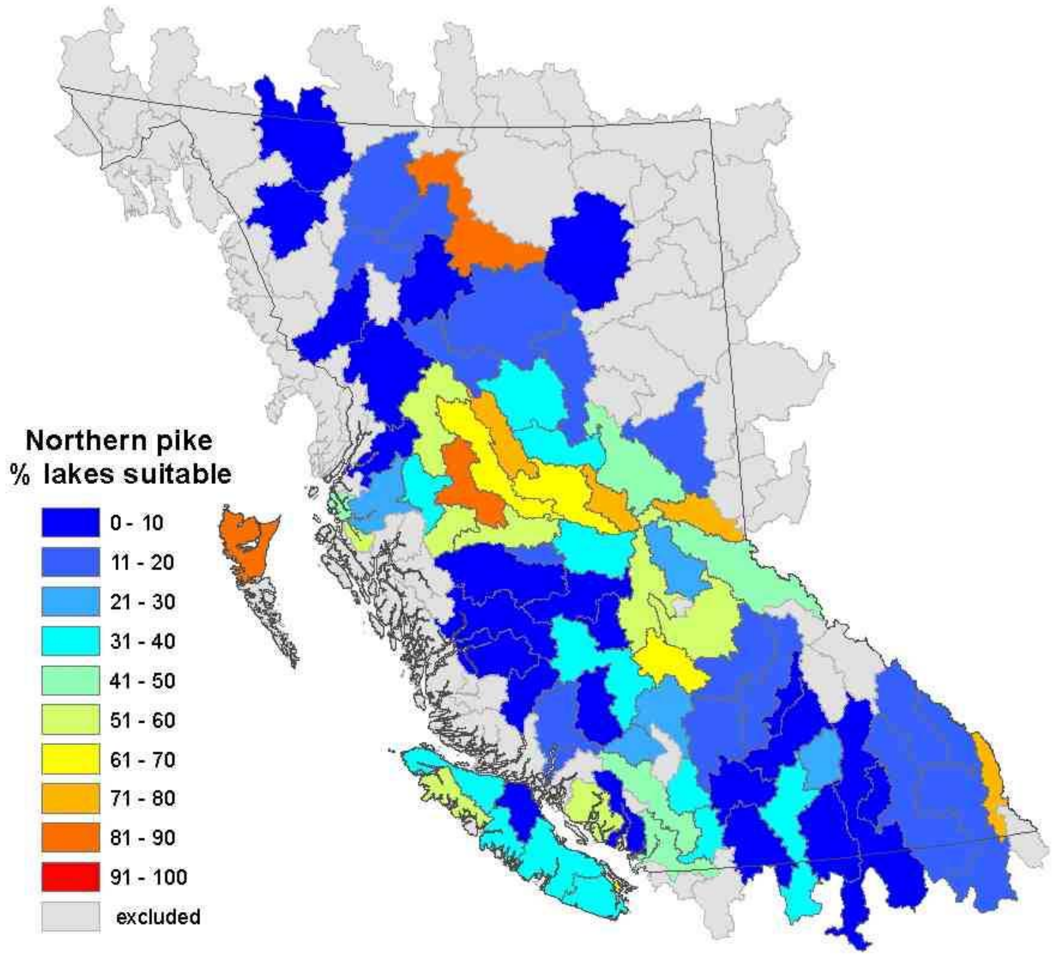


Figure 3.2. Results of the habitat suitability model for northern pike. For each watershed, the proportion of lakes predicted to be suitable for pike is indicated by the colour. Watersheds with less than 5 lakes with data are excluded.

3.4 Aquatic Organism Ecological and Genetic Risk Assessment

3.4.1 The probability of the organism arriving, colonizing and maintaining a population.

Northern pike are native to northern BC. Pike have spread into southern BC from transboundary rivers in the Columbia region. Future arrivals could be the result of illegal transfers from the US, Alberta or northern BC. The presence of only one identified illegal introduction in southern BC suggest that there is less interest in this species, or it is more difficult to translocate, than for the other species in this review.

The successful introduction of northern pike to many locations in the western United States suggests a reasonable probability of establishment once introduced (McMahon and Bennett 1996). Pike stocking programs exist in many jurisdictions, and on occasion pike are introduced into waterbodies to control other non-desirable fish species. In Sweden, Spens et al.

(2007) found pike were established in 100% of small boreal lakes that were connected to an upstream source population. Unfortunately no one has summarized the overall success rate of population establishment from stocking records.

Apart from the requirement for appropriate environmental conditions such as water temperature, the probability of a pike population becoming established in significant numbers in a waterbody is probably related to the presence of slow moving riverine habitats with cover in the form of submerged vegetation or debris, or shallow littoral zones with flooded vegetation.

3.4.2 The probability of spread.

The range of northern pike has expanded mainly by deliberate human introductions, with an important secondary vector of spread via movements to connected waterways, when suitable conditions occur. Although not an active migratory species, a few individuals in pike populations appear to undergo long distance movements that undoubtedly contribute to species spread (Tyus and Beard 1990). Downstream movement contributed to colonization in boreal lakes in Sweden (Spens et al. 2007). Flinders and Bonar (2004) provide examples of downstream spread from stockings in lakes and reservoirs in the US southwest. In Sweden, upstream colonization was restricted by the presence of higher gradient reaches in rivers connecting lakes (Spens et al. 2007). In southcentral Alaska the initial introduction of pike into a headwater lake has resulted in pike spreading throughout Cook Inlet streams (characterized as an area as large as Indiana) in 40 years (Rutz 1996). Locally, introductions into the Kootenay River in Idaho appeared to have lead to the spread of the species into the Koocanusa Reservoir in southern BC.

Northern pike may also spread as a result of deliberate human actions by those that consider it a desirable sports fish. Recent illegal pike introductions in California (Moyle 2002), Nevada and Arizona (Flinders and Bonar 2004), the Pacific Northwest (McMahon and Bennett 1996) and elsewhere (Spens et al. 2007) highlight the significance of this risk.

3.4.3 Final rating: widespread establishment of pike.

Table 3.3. The probability of arrival, survival and reproduction, spread, and widespread establishment once arrived (WEOA) of northern pike.

	Vancouver Island		Lower Mainland		Upper Fraser		Thompson		Columbia		Arctic Drainage		Central & N Coast	
Element	Rank	Un	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc
Arrival	L	L	L	L	M	M	L	M	M*	M	A		L	M
Surv. & Reprod.	M	M	M	M	M	M	M	M	M	M	A		M	M
Spread	M	M	M	M	H	M	H	M	H	M	A		L	H
WEOA	M	M	M	M	M	M	M	M	H	M	A		L	H

Notes: Northern pike are native to the Arctic region and are not considered here. Northern pike are also native to a few watersheds in the north coast region but these are ignored in the table. For arrival, the Columbia ranking applies to the Okanagan basin.

3.4.4 The ecological impact on native ecosystems.

Although pike can potentially compete with other species for common food resources, their main impact on native ecosystems is expected to be the result of predation - northern pike begins a piscivorous lifestyle at 20 mm TL. Within their native range pike populations have been shown to strongly influence prey fish communities. For example, Robinson and Tonn (1989) found that fish communities in Alberta lakes were a function of pike presence: cyprinids were generally absent from lakes with pike. Experimentally introducing pike into lakes that previously did not contain them resulted in reductions and sometimes extirpations of small fishes (He and Wright 1992; Findlay et al. 2000). Most vulnerable were small soft-bodied fishes such as cyprinids; species with large adult sizes or spiny rays were less impacted by pike introduction. The introduction of pike also had a cascading effect on the lake food web as the reduction in planktivorous prey fish can lead to increases in zooplankton and benthic invertebrate abundance. Finally, reductions in native fish diversity have been related to the presence of pike and other non-native piscivores in eastern North America (Chapleau et al. 1997; Findlay et al. 2000) and Europe (Rincon et al. 1990; Bystrom et al. 2007).

Published accounts of the effects of northern pike introductions on native fishes in western North America are few and largely anecdotal in nature (McMahon and Bennett 1996). Salmonids are often found in the stomachs of pike, reflecting their preference for soft-bodied fishes compared to sticklebacks or introduced centrarchids (Bennett and Rich 1990; Flinders and Bonar 2004). Flinders and Bonar (2004) estimated that pike consumed 63% of small (<120mm TL) rainbow trout stocked into an Arizona lake. The impact of pike predation was lower in two other lakes they examined, partly because of the larger size of the stocked trout. Flinders and Bonar (2004) also provide narratives of other cases where the stocking of hatchery rainbow trout has proven unsuccessful in western reservoirs where pike are present.

Northern pike are not native to the southern half of Alaska, but were first introduced to the headwaters of the Susitna River in the 1950s (Rutz 1996). Pike have since spread throughout the watershed and have invaded other Cook Inlet streams, an invasion that has been assisted by unauthorized introductions and the species tolerance of brackish water in the inlet. Salmonids have been found to be very common in the stomachs of northern pike and were taken in preference to sticklebacks or invertebrates (Rutz 1999). Coho salmon juveniles, which tend to prefer slower moving off-channel habitats and the littoral zones of lakes, were common in pike diets, as might be expected given their overlap in habitat preferences. In very small lakes sockeye salmon were also common in pike diets. Pike were found to concentrate at lake outlets to predate on migrating salmon smolts. Although the evidence presented is somewhat anecdotal, Rutz (1999) suggests that declines in the occurrence and abundance of both rainbow trout and coho salmon in the Susitna River has been the result of the northern pike invasion.

The threat of pike introductions on native fishes has prompted agencies to development management and eradication plans to minimize the negative impacts associated with pike predation. Most notable is the failed attempt to use rotenone in Davis Lake, California to minimize the threat of pike moving downstream and invading the Sacramento River valley (Aguilar et al. 2005). A management plan has been developed for pike in southern Alaska because of the threat to salmon populations (SANPCC 2006).

Based on the limited literature available northern pike can be considered a threat to native biota in western North America. That threat is perhaps greatest in small, shallow lakes where all soft-bodied fishes are potential prey. In larger lakes pike can become established in the littoral zones if vegetation exists, and will impact fish that also use those habitats. Low gradient rivers with off-channel sloughs and wetlands will also be habitats where pike will impact native fish species. It is unclear whether introduced pike will lead to dramatic alterations to aquatic communities in larger ecosystems as conditions will not always permit the establishment of a large pike population (e.g., Bennett and Rich 1990). Such is the case in the Koocanusa reservoir in southeastern BC.

3.4.5 Genetic impacts on local self-sustaining stocks or populations.

The origins of introduced pike in the Pacific Northwest have not been identified. A genetic analysis of introduced pike in a California reservoir also failed to identify the source of this illegal introduction, although such analyses may be difficult because of relatively low genetic variability in the species (Aguilar et al. 2005). The potential for pike introductions from southern BC to interbreed with native pike populations of the Mackenzie, Yukon and other northern river basins seems unlikely unless there is a dramatic escalation of unauthorized interbasin transfers from south to north in the province. Thus there appears little risk of genetic impacts by introduced pike on native northern BC populations.

Pike are known to hybridize with the muskellunge (*E. masquinongy*); most offspring are sterile and are called “tiger muskie”. Cultured tiger muskies are stocked for sports fishing in Idaho and elsewhere. Muskellunge are not native to BC. Pike are unlikely to hybridize with any other native species in BC.

3.4.6 Final rating: ecological and genetic consequences.

Table 3.4. The magnitude of the ecological and genetic consequences and their uncertainties for introduced northern pike in British Columbia.

	British Columbia	
Element	**Magnitude**	**Uncertainty**
Ecological Consequence:	Very High	Low
Genetic Consequence	Very Low	Low

3.4.7 The aquatic risk potential for northern pike.

The summary ranks for the probability of establishment (introduction, survival, and reproduction) and the ecological and genetic consequences are combined in Tables 3.5 and 3.6 to obtain the overall risk rating.

Table 3.5. Matrix for overall ecological risk by region.

Ecological Consequences						
	Very High					
	High		CC, NC	VI,LM,UF,TH	CO	
	Medium					
	Low					
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

Table 3.6. Matrix for overall genetic risk, by region.

Genetic Consequences						
	Very High					
	High					
	Medium					
	Low					
	Very Low		CC,NC	VI,LM,UF,TH	CO	
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

3.5 Pathogen, Parasite or Fellow Traveler Ecological and Genetic Risk Assessment

3.5.1 The probability that a pathogen, parasite or fellow traveler may be introduced along with the potential invasive species and become established.

Pike introductions in BC will likely result from movements of fish from established populations along the US border or illegal movements from northern BC or Alberta. Fish illegally introduced are unlikely to be screened or treated for disease. Therefore any parasites or pathogens on or in these fish will likely accompany their hosts.

Many of the parasites found in pike are generalists common to many fish species (Dick and Choudary 1996) and those introduced with pike will likely find suitable hosts. It is unclear whether those parasite species that are specific to pike will encounter the secondary hosts required to complete their life cycle. One notable exception is *Triaenophorus*, which has the potential to infect trout and salmon populations, causing mortality or loss of flesh quality (Uzmann and Hesselholt 1957).

Table 3.7. Probability and uncertainty for the establishment of parasites and pathogens from introduced northern pike.

	British Columbia	
Element	**Probability**	**Uncertainty**
Establishment	High	High

3.5.2 The ecological and genetic impacts of a pathogen, parasite or fellow traveler on native species and ecosystems.

No disease outbreaks or other effects of parasites or pathogens on native biota have been identified for introduced pike populations. There may be some risk of novel parasites unique to pike infecting native biota if pike are introduced outside of their native range. The risk of *Triaenophorus* infections is reflected in the higher rating (Table 3.8). No information is available on the genetic risks of traveler organisms.

Table 3.8. Estimated consequences of the introduction of parasites, pathogens, or fellow travelers from introduced northern pike populations.

	British Columbia	
Risk Component	**Impact**	**Uncertainty**
Ecological	Moderate	Very High
Genetic	Low	Very High

3.5.3 The aquatic risk potential for pathogen, parasite or fellow traveler.

The summary ranks for the probability of introduction and the consequences are combined in the following table to obtain an overall risk rating for fellow travelers.

Table 3.9: Matrix for determining overall risk for parasites. The solid ellipse is for ecological impacts, the dashed ellipse is for genetic effects.

Ecological or Genetic Consequences	Very High					
	High					
	Medium					
	Low					
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

4. PUMPKINSEED

4.1 Background and Biology

As with all of the Centrarchids, *Lepomis gibbosus* is an anatomically advanced freshwater fish with spines on their dorsal, anal, and pelvic fins, two combined dorsal fins, pelvic fins situated well forward on their bodies, and rough ctenoid scales (McPhail 2007). It is a small (rarely greater than 200 mm, although up to 250 mm in some lakes) attractive fish that is laterally compressed with a deep body. Larger pumpkinseed are olive-coloured and have distinctive orange and blue cheek stripes (Wydoski and Whitney 2003). The juveniles lack these bright markings and have a silvery appearance. All pumpkinseed have an opercular flap with a black centre, light margins, and a red (sometimes orange, pink, or yellow) crescent moon-shaped spot at its posterior edge (McPhail 2007; Scott and Crossman 1973). This red spot distinguishes *L. gibbosus* from the only other *Lepomis* species in British Columbia, *L. macrochirus* (the bluegill sunfish) which in contrast has a blue-black opercular flap spot. Pumpkinseed have pronounced sexual dimorphism with the males slightly more colourful than the females (McPhail 2007). During the breeding season sexually mature males are particularly brightly coloured with irregular blue lines on the sides of the head and bronze sides with an irregular pattern of lighter wavy lines and an orange underside. The females have more prominent dark vertical bands than males while in breeding mode.

The only information on the biology of pumpkinseed in British Columbia is in a study of introduced fishes in the Creston Valley population (Forbes 1989). Therefore most of the following information comes from other areas and is reviewed in Scott and Crossman (1973) and McPhail (2007).

Sexual maturity in the pumpkinseed is usually reached by age two although some mature at age 1 and the size and age at maturity depends on environmental conditions. The breeding season for pumpkinseed occurs continuously in the spring and summer when the water temperatures range between 15 ºC and 25 ºC (Forbes 1989). Male pumpkinseed exhibit a large amount of parental care, first creating a spawning nest (shallow and 100-400 mm in diameter) in waters less than 1 m deep, and then vigorously guarding and fanning the eggs and larvae following mating. Depending on female size, they produce typically 600 to 3 000 (up to 12 000) sticky, demersal eggs that are roughly 1 mm diameter. They release them in batches and sometimes in more than one male’s nest. The eggs take as little as 3 days to hatch at 28 ºC or longer depending on the temperature of the surrounding water. After hatching the male continues to guard the fry for about one week, catching them in his mouth to keep them near the nest. After the fry have left the nest, the male may clean the nest in preparation for another spawning. Nests are often located near submerged vegetation in various substrates and are clustered in large groups, causing significant habitat alteration.

Growth of the juveniles is relatively fast with young-of-the-year in Ohio reaching 20-81 mm in length by October (Scott and Crossman 1973). By their second year (the frequent age of maturity) they were found to reach roughly 100-150 mm. Growth slows with the age of the fish, and pumpkinseed reach their maximum size of roughly 200 mm by about 7-9 years, depending on the lake. In small productive water bodies with large population size, stunting takes place and a maximum of 100-130 mm may be achieved (Heath and Roff 1987). This suggests that intraspecific competition can be severe.

The pumpkinseed is usually found in quiet, slower moving streams and the waters of small lakes, ponds, and the shallow weedy bays of larger lakes (Scott and Crossman 1973). It prefers clear water and areas with submerged vegetation or brush. They can be found in large aggregations and often make up the largest portion of the fish population in small water bodies with warm water. Adults are generally found in pairs or smaller loose aggregations and littoral forms (see below) stay close to the shoreline near submerged vegetation. Their upper lethal temperature when acclimated at 18 and 24 ºC was found to be 28 and 30 ºC, respectively (Scott and Crossman 1973). Feeding was seen to decrease at temperatures below 15 ºC in a shallow Ontario pond (Collins and Hinch 1993) and a thermal preference for warmer waters may limit the northward spread of pumpkinseed. Juvenile pumpkinseed occupy the same habitats as adults although once newly hatched larvae fill their swim bladders they leave the nest and move to open water for a period of time before moving back to the littoral area (McPhail 2007). Although most habitat information comes from eastern North America, observations suggest that the situation in BC is similar.

The pumpkinseed has a morphology that is specialized for feeding on hard-bodied food items (Osenberg and Mittelbach 1989), although their diet can be quite flexible. Prey selection varies with fish age, prey availability, habitat, season, and presence of other fish species although mainly consists of invertebrates in most areas (McPhail 2007). In water bodies where pumpkinseed and bluegill co-occur, pumpkinseed feed in the littoral (nearshore) zone on large bottom dwelling invertebrates such as snails and have short and widely spaced gill rakers. Their diet has been known to consist of more than 80% gastropods (Osenberg and Mittelbach 1989). Bluegill feed in the pelagic (open water) zone on zooplankton, and have gill rakers that are long and pointed, and better adapted to feeding on small planktonic prey (Robinson et al. 2000). In sympatry, bluegill outnumber pumpkinseed by 6 or 10 to 1 (Robinson et al. 1993). In British Columbia, the pumpkinseed co-occurs with the bluegill sunfish in Osoyoos Lake and possibly other locations in the Okanagan drainage system (McPhail 2007).

In some lakes without co-occurring bluegill sunfish there are two behavioural and morphological types of pumpkinseed – a littoral, benthic feeder with short and stubby gill rakers consuming mainly snails and aquatic insect nymphs, and a limnetic feeder with thicker, more closely-spaced gill rakers that consumes mainly plankton (Robinson et al. 1993; Gillespie and Fox 2003; Parsons and Robinson 2007). Other aspects of morphology also differ between the two morphotypes, reflecting the different demands of their habitats. The pumpkinseed's ability to adapt to their environment shows a high degree of morphological plasticity. In British Columbia, the majority of populations exist in conditions that should favour the formation of the two morphotypes (Robinson et al. 2000), and therefore the two forms may exist there (McPhail 2007).

When in locations with or without bluegill, adult pumpkinseed can feed on amphibians and small fishes including smaller pumpkinseed (Scott and Crossman 1973). The young pumpkinseed feed on zooplankton, the same prey as bluegill (Robinson et al 1993). In the presence of bluegill they have an ontogenetic switch to large benthic macroinvertebrates including mollusks and nymphs. In lakes without bluegill, some remain in the limnetic zone and continue to consume zooplankton. In their native range, young pumpkinseed are the food of many predatory fishes including basses, walleye, yellow perch, northern pike, muskellunge (*E. masquinongy*), larger pumpkinseed, and other sunfishes (*Lepomis* spp.; Scott and Crossman 1973).

A large number of fellow travelers have been identified for the pumpkinseed over its whole range. Hoffman (1967) listed over 104 parasites that have been known to be associated with pumpkinseed including 5 protozoans, 60 trematodes, 8 cestodes, 14 nematodes, 7 acanthocephalans, 3 leeches, 6 crustaceans, 1 linguatulans, and an unidentified number of molluscs. One parasite frequently on this species is the black-spot, the resting phase of a trematode, with the belted kingfisher being the final host. This parasite causes black spots on the fins (McPhail 2007).

Another parasite, the small (0.6-1.0 mm) parasitic copepod *Neoergasilus japonicus* which is native to eastern Asia, was found in pumpkinseed, largemouth bass, yellow perch, and fathead minnow (*Pimephales promelas*) in Lake Huron in 1994 (Hudson and Bowen 2002). By 2001 seven additional species (including smallmouth bass) were found with the parasite in this lake. The parasite can swim well, can be found on a variety of hosts (from cyprinids to percids and centrarchids to ictalurids), and is able to move from one host to another easily. This may explain how this copepod appears to have dispersed over long distances quite quickly, spreading across Europe in 20 yr and moving into North America over 10 yr. The mode of transport and introduction into the Great Lakes is probably by exotic fish species associated with the fish husbandry industry, the aquaculture trade, or bait releases. The ecological impacts of the non-native parasite is unknown, although they appeared to reduce growth in some species of fish.

4.2 Known Distribution

The native distribution is restricted to North America. *L. gibbosus* is native to the lowland freshwaters of eastern North America from New Brunswick to Georgia along the Atlantic coast (Scott and Crossman 1973, McPhail 2007). West of the Appalachian Mountains its native range includes the region from the southern portion of Quebec to southern Ohio and west to northern Missouri and eastern South Dakota and north through eastern Manitoba and western Ontario. Its introduced range now includes much of western North America and elsewhere in the world (McPhail 2007). The distribution of pumpkinseed in British Columbia is currently limited to the southern portion (Figure 4.1). There are populations in 4 our 8 regions in British Columbia (Table 4.1).

Table 4.1: Counts of waterbodies containing introduced pumpkinseed, by region, in British Columbia, from Runciman and Leaf (2008).

	Region						
Category	Vancouver Island	Lower Mainland	Upper Fraser	Thompson	Columbia	Arctic	C and N Coast
Confirmed	55	26	0	2	21	0	0
Unconfirmed	0	2	0	1	6	0	0

Figure 4.1. Distribution of known (confirmed) occurrences of pumpkinseed in British Columbia (data from Runciman and Leaf 2008).

4.3 Potential Distribution

Based on the distribution in eastern Canada, areas of BC with >1750 DD were considered to have a favourable climate for pumpkinseed, and areas of 1500-1750 DD were probably suitable. These conditions were met in much of southern BC, with the exception of the higher elevation areas in the mountains. The northern limit to pumpkinseed in the interior appears to be the southern Caribou Plateau (Fig 4.2). Areas of the BC coast were also predicted to be warm enough although mid-summer lake temperatures along the coast may not be sufficient for egg and larval development.

Figure 4.2. The Atlas of Canada Growing Degree-Days map. The best habitat for pumpkinseed was considered to have >1750 DD. Some lakes may be suitable at 1750-1500 DD; areas with <1500 DD were considered unsuitable. Reproduced with permission of Natural Resources Canada.

4.4 Aquatic Organism Ecological and Genetic Risk Assessment

4.4.1 The probability of the organism arriving, colonizing and maintaining a population.

Dextrase and Mandrak (2006) identified seven pathways for the introduction of non-native species of flora or fauna that threaten Canadian freshwater fishes. Over 65% of introductions were related to sport fishing, including the stocking of sport fish and stocking of forage fish for sport fish – most of which are unauthorized. Other means of introduction for fishes include ballast water discharge, aquarium fish releases, canals, and aquaculture escapes. Once introduced, these species often spread beyond the area of introduction by way of natural dispersal.

Introductions of pumpkinseed into British Columbia likely originally occurred through the Columbia River system from Washington and Idaho and have spread to other parts of southern BC (McPhail 2007). In addition to its presence in the Columbia River system of BC, pumpkinseed currently exist in the upper Kootenay River, Pend d'Oreille, and Okanagan river systems as well as in the lower Fraser Valley and southeastern Vancouver Island. Their present scattered distribution in BC suggests human intervention as the main vector. On southern Vancouver Island there are records of deliberate introduction in Ministry of Environment, Lands, and Parks records for two lakes in 1901 and 1923 (Jordan et al. 2008). On Vancouver Island the first population was likely introduced with smallmouth bass, however they now also occur in lakes without bass (McPhail 2007). Their occurrence in some BC lakes prior to the introduction of larger sport fish such as bass suggests that they have been deliberately introduced as a prey item for the sport fish. As well, for the pumpkinseed, the aquarium trade appears to be a large cause of the spread in British Columbia (McPhail 2007). People keep this attractive fish in their tanks until they become too large, at which time they are released into the nearby lakes or streams. Therefore, the arrival or the pumpkinseed into areas where it does not currently exist is likely to occur by human intervention. The probability of arrival of pumpkinseed into the eight Regions is determined by the current distribution of the pumpkinseed and the number of water bodies in the surrounding area as well as the settlement of humans (for the aquarium releases).

A high level of life history plasticity in the pumpkinseed appears to have contributed to its ability to become established in new locations and then to succeed as invaders (Fox et al. 2007). Pumpkinseed in the Iberian Peninsula are able to adopt a more opportunistic life history strategy (earlier maturation, smaller size at maturity, higher gonadosomatic index) in areas where they are newly introduced than where they are established. In areas where they have already established high densities their more K selected life history traits allow them to be successful in a competitive environment (their later maturation, larger size at maturity, lower gonadosomatic index, as well as parental care of eggs and larvae). Other factors including the large amount of parental care increase the probability of establishment (Hatfield and Pollard 2006).

However, the reproductive behaviour of pumpkinseed requires specific conditions and if those conditions are not met establishment may be difficult. Thus in water bodies where there is little access to the types of habitat required for nest building and reproduction, or the types of prey for the young, the risk of establishment of pumpkinseed would be lower than based on climatic considerations alone.

The probability of arrival into regions where the pumkinseed is not currently present was assessed mainly on the strength of human vectors.. Since the Central Coast, North Coast, and Upper Fraser regions are in fairly close proximity to existing populations of pumpkinseed, yet the visitation to/population in the regions is not as high as some of the other regions, the probability of arrival there is low, low, and moderate, respectively. The uncertainty was considered high since it is only plausible and based on knowledge of past introductions. The probability of arrival to the Artic region is very low with a high uncertainty due to the distance from existing populations and the low visitation/population density there.

4.4.2 The probability of spread.

Pumpkinseed successfully spread to and colonize new areas once introduced. They are one of the most successfully introduced species of fish in Europe (DeClerck et al. 2002; Fox et al. 2007). They were introduced into Europe in the late 19th century and are now established in 28 countries in Europe and Asia Minor (Fox et al. 2007). Their ability to spread is a result of their ability to adapt to novel environments (Bhagat et al. 2006) as well as parental care of young pumpkinseed (Hatfield and Pollard 2006). The pumpkinseed has dispersed farther north than the other *Lepomis* species and may do better in Canada than in the more southern parts of its range (Scott and Crossman 1973). However, it was found that adult body size significantly decreased with increasing latitude in native North American populations (Copp et al. 2004), suggesting that the cooler temperatures or shorter growing seasons may not be as favourable for this species.

The pumpkinseed's present scattered distribution in BC suggests human intervention as the main vector, although natural dispersal from the site of introduction has also occurred. Limiting the spread (or rate of spread) of the pumpkinseed are some of its tendencies. Because of a preference for slow moving waters, the probability of it spreading without human intervention through watersheds with fast-flowing rivers may be reduced. The pumpkinseed is highly territorial, potentially limiting its spread. In a mark and recapture experiment in a lake with both littoral and limnetic ecotypes of pumpkinseed, Scott and Fox (2004) found that both formes exhibit a high degree of habitat or site fidelity. However, it is possible that an increase in the density of the pumpkinseed in a given water body may increase the chances of straying from the home site as has been seen in other fish species (Ware et al. 2000).

Spreading may not only be accomplished by the adults but also by the younger pumpkinseed. After newly-hatched larvae fill their swim bladders they leave the nest and move to open water before they move back to littoral areas (McPhail 2007). At the limnetic stage they are less territorial and may have the opportunity to disperse through areas that do not contain littoral habitat along the pathway.

The probability of the pumpkinseed spreading within the regions that it has already inhabited (Table 4.1; Table 4.2; Figure 4.1) varies due to the past history of spread, the density of human populations or visitations, as well as the connectedness of the waterways in the region. The uncertainty ratings varied depending on whether the spread of the species in the region had already been observed.

4.4.3 Final rating: widespread establishment of pumpkinseed.

Table 4.2. The probability of arrival, survival and reproduction, spread, and widespread establishment once arrived (WEOA) of the pumpkinseed for the eight regions of British Columbia with the associated uncertainties.

	Vancouver Island		Lower Mainland		Upper Fraser		Thompson		Columbia		Arctic Drainage		Central Coast		North Coast	
Element	Prob	Unc	Prob	Unc	Prob	Unc	Prob	Unc	Prob	Unc	Prob	Unc	Prob	Unc	Prob	Unc
Arrival	A		A		M	H	A		A		VL	H	L	H	L	H
Survival & Repro	H	L	VH	L	L	H	H	M	M	M	VL	M	L	L	L	H
Spread	H	VL	VH	VL	M	L	H	L	VH	VL	L	H	L	M	L	M
WEOA	H	L	VH	L	M	H	H	M	VH	M	VL	H	L	M	L	H

4.4.4 The ecological impact on native ecosystems locally and within the region.

Introduced species in general are a primary factor in four out of five extinctions of Canadian freshwater fishes and a secondary threat for other species (Dextrase and Mandrak 2006). *L. gibbossus* poses a potentially significant ecological risk to the native fauna of British Columbia. Dextrase and Mandrak (2006) noted that pumpkinseed were considered a threat to 7 out of 41 endangered species in Canada , second only to the brown bullhead (*Ameiurus nebulosus*). Two introduced fish families, the sunfishes (Centrarchidae) and the bullhead catfishes (Ictaluridae) were shown to affect more native listed species than any of other families in both Canada and the US (Dextrase and Mandrak 2006).

The pumpkinseed is a small and not highly piscivorous fish, however, as McPhail (2007) put it "this attractive little fish is a pest". Since in small productive lakes, populations of pumpkinseed can become stunted, it suggests that there is serious intraspecific competition and resource depletion. This is bound to influence the native species that it coexists with through interspecific competition for resources. The pumpkinseed competes with native species and its introduction on Vancouver Island has resulted in the extirpation of scientifically important stickleback (*Gasterosteus* spp.) populations (McPhail 2007).

The impacts of pumpkinseed introductions in Europe have been documented in a number of studies. For one shallow lake in Portugal, Lake Vela, the pumpkinseed was introduced in the late 1990s and has already become the dominant taxon in the lake (Castro et al. 2007). In a Mediterranean river in years with low flow, introduced pumpkinseed increased in numbers and strongly dominated the fish assemblage (Bernardo et al. 2003). The indigenous populations decreased in abundance and a previously common endemic cyprinid (*Anaecypris hispanica*) became one of the most endangered fishes in Europe. In high flow years with flood events, the pumpkinseed populations decreased and the cyprinid population, which appeared more adapted to flood events, increased again. Garcia-Berthou and Moreno-Amich (2000) found that the introduction of 12 exotic species, including pumpkinseed, resulted in the extirpation of two native species and the reduction in abundance of three others. Currently the fish assemblage is dominated by three of the exotic species – largemouth bass and pumpkinseed in the littoral zone and roach (*Rutilius rutilus*) in the pelagic zone. Only one of the original 5-6 native species is common today (*Blennius*).

Co-existence of native fishes and introduced pumpkinseed appears to be possible in some lakes. In Europe, pumpkinseed have rarely been found to feed primarily on mollusks as they do in many North American populations (Rezsu and Specziar 2006). Following the ontogenetic shift from planktivory, European pumpkinseed fed mainly on chironomids and amphipods. These are also the most important prey of native species including ruffe (*Gymnocephalus cernuus*) and perch (*Perca fluviatilis*). However, in Lake Balaton, these species appear to effectively partition their food throughout their life span to avoid interspecific competition.

Pumpkinseed as well as other fish introduced from eastern North America preferred the same habitats as the juvenile coho salmon in the Pacific Northwest – shallow, off channel areas such as ponds, sloughs, marshes, and the littoral zones of lakes (Bonar et al. 2005). The results of a survey of three shallow lakes over a two year period indicated that the pumpkinseed did not consume juvenile coho salmon, although some of the other introduced fishes, including largemouth bass did. Thus, pumpkinseed did not appear to directly impact the juvenile coho salmon. Because the growth rate of the coho was higher than in neighbouring streams, Bonar et al. (2005) concluded that competition between the coho and the introduced fishes including the pumpkinseed did not limit the coho populations.

Osenberg and Mittelbach (1989) found that the pumpkinseed's propensity for consuming snails in the littoral area resulted in a reduction in the abundance of snails. Another study demonstrated that introduced pumpkinseed had an impact on the abundance and species richness of native snails in laboratory and field cage experiments (Lodge et al. 1998). However, they did not find this effect in a survey of 21 northern Wisconsin lakes.

One of the main food items of pumpkinseed, the freshwater snail, *Physa spp.* exhibits predator-induced plasticity in its shell morphology (DeWitt et al. 2000). In the presence of crayfish predators, *Physa* tend to adapt to the shell entry mode of attack, by elongating its shell. In the presence of shell crushing fish like pumpkinseed, it adapts by forming a more rotund shape that is more crush resistant than the elongate form. Therefore, for *Physa* in a waterbody that contains endemic crayfish, then the elongate form will offer less protection from pumpkinseed predation, making the native snail population more vulnerable to this introduced species.

The reduction in snail density through predation by pumpkinseed can indirectly influenced the biomass and species composition of epiphytic algae (Broenmark 1989). The snails consume epiphytic algae and a reduction in snail density due to pumpkinseed predation reduced this grazing and results in an increased biomass of algae. This increased biomass of algae was found to indirectly affect snail-epiphyton-macrophyte interactions: lowered snail density decreases the grazing of epiphytes from macrophytes, thus reducing the benefit that grazing gives the macrophytes in the form of reduction from shading and competition for nutrients.

Because the pumpkinseed excavates the bottom of the littoral areas for its nest building, it has the potential to cause significant habitat modification and disturbance. Thorp (1988) found that these disturbances resulted in a reduction in benthic invertebrate diversity and density, and that these affects were long lasting in that they were partially detectable the year following the nesting behaviour.

Pumpkinseed introduction has also been shown to alter zooplankton behaviour and life history in response to predation. Hartleb and Haney (1998) showed in a laboratory experiment that *Daphnia pulex* was able to decrease its vulnerability to predation by pumpkinseed by moving into areas of low light and thermal stratification. Thermal stratification and reduced oxygen levels below the thermocline can allow large zooplankton to exist with planktivores. In the presence of predation by pumpkinseed, *Daphnia longispina* in Lake Vela, Portugal increased the production of offspring, resulting in a higher fitness relative to the control without fish (Castro et al. 2007). The presence of these fish also induced an earlier first reproduction, a smaller size at maturity, and smaller offspring. The method of induction appears to be chemical cues that the pumpkinseed and other predators produce.

Aside from the predation on snails, most of the studies above show indirect effects of the pumpkinseed on different trophic levels. They are not known as piscivores, and most impacts occur through competitive interactions. Pumkinseed have caused or contributed to the extinctions of important stickleback species pairs and the alteration of fish assemblages in water bodies in Europe, which have also resulted in extinctions. These observations suggest that the magnitude of ecological impact is very high in small warm lakes and other small water bodies, where pumpkinseed often make up the largest proportion of the fish population (Table 4.4). The evidence in Canada (and in British Columbia: Vancouver Island stickleback population extirpation) suggests that the uncertainty of this impact is low. The impact rating for large lakes and other water bodies is moderate as pumpkinseed are able to use a smaller proportion of the habitat and are less likely to cause resource depletion.

4.4.5 *Genetic impacts on local self-sustaining stocks or populations.*

Pumpkinseed are known to hybridize with warmouth (*Lepomis gulosus* (Cuvier)) and the longear (*L. megalotis*), green (*L. cyanellus*), orangespotted (*L. humilis*), redbreast (*L. auritus*), and bluegill (*L. macrochirus*) sunfishes in the wild (Scott and Crossman 1973). Bluegill is the only other *Lepomis* species in British Columbia (McPhail 2007), and so there is no genetic risk to the other *Lepomis* species in BC. However, bluegill is not a native fish of BC (Scott and Crossman 1973; Wydoski and Whitney 2003) and so hybridization with this species is not considered a genetic risk to native populations. Therefore, pumpkinseed do not pose a genetic risk to native populations in BC. In fact, all centrarchids (sunfish, bass, and crappie) in BC are introduced because tectonic and glacial events eliminated ancient species from northwest of North America (McPhail 2007). Therefore the magnitude of the genetic impact of largemouth bass on native populations is very low with a low degree of uncertainty (Table 4.4).

When pumpkinseed co-occur with bluegills in their native range they often form hybrids (Konkle and Philipp 1992; McPhail 2007). Hybrid sunfishes are frequently fertile and are able to breed with other hybrids as well as one or both parents (Scott and Crossman 1973). Hybridization between the pumpkinseed and bluegill is the most common and occurs to such an extent that in some lakes in eastern Ontario it is difficult to distinguish the parental species. Thus far, hybridization doesn't pose an identification problem in British Columbia, however, if bluegills become more common in the Osoyoos-Oliver region, hybridization between these species could occur (McPhail 2007)

4.4.6 *Final rating: ecological and genetic consequences.*

Table 4.3. The magnitude of the ecological and genetic consequences and their uncertainties for introduced pumpkinseed in British Columbia.

	British Columbia	
Element	**Magnitude**	**Uncertainty**
Ecological Consequence: Small Water Bodies	Very High	Low
Ecological Consequence: Large Water Bodies	Moderate	High
Genetic Consequence	Very Low	Low

4.4.7 *Aquatic risk potential for pumpkinseed.*

The summary ranks for the probability of widespread establishment (introduction, survival, reproduction, and spread; Table 4.2) and the ecological and genetic consequences (Table 4.3) are combined in Table 4.4 to obtain an overall risk rating.

Table 4.4. Matrix for determining overall risk, by region. The dotted ellipses are for the ecological consequences estimate for small water bodies and the solid ellipses are for large rivers and lakes.

Ecological Consequences						
	Very High	AR	CC, NC	UF	VI, TH	LM, CO
	High					
	Moderate	AR	CC, NC	UF	VI, TH	LM, CO
	Low					
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

Table 4.5. Matrix for determining genetic risk, by region.

Genetic Consequences						
	Very High					
	High					
	Moderate					
	Low	AR	CC, NC	UF	VI, TH	LM, CO
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

4.5 Pathogen, Parasite, or Fellow Traveler Ecological and Genetic Risk Assessment

4.5.1 The probability that a pathogen, parasite, or fellow traveler may be introduced along with the potential invasive species and become established.

The primary mode of introduction into new lakes in British Columbia results from unauthorized introductions from nearby water bodies for the use as a prey fish for sport fisheries and as a result of the release of aquarium fish (McPhail 2007). With the former method of introduction, the pumpkinseed that are transferred are likely to take with them parasites that already exist in BC. For the latter method, there is a possibility that if the aquarium fish came from another area that they may carry with them novel parasites.

Steps are being taken to prevent such transfers of parasites. In October 2006, the United States Department of Agriculture's Animal Plant Health Inspection Service (USDA-APHIS) issued a federal regulation preventing the transport of numerous non-native species, including the pumpkinseed, from eight states surrounding the Great Lakes area. Included in this regulation is the prevention of import of pumpkinseed from Ontario and Quebec. This regulation was to prevent the spread of viral hemorrhagic septicemia (VHS) (which has copepods as its carrier) to aquaculture sites for pumpkinseed and other non-native species. It will also likely stem the spread of other parasites as well.

The majority of the aquaculture producers of sunfish in the United States are in Texas and Wisconsin (Jordan et al. 2008). The purpose of these facilities is mainly for stocking sport fish ponds and lakes or for bait fish production and scientific research. These locations are far from BC and so the likelihood of introductions from these facilities is low.

The potential future distribution of the pumpkinseed identified above was based on a habitat model that uses the conditions in lakes that support pumpkinseed in eastern Canada to predict which lakes in BC would support pumpkinseed. Thus, it is likely that the conditions that would support the pumpkinseed would also support the common parasites that pumpkinseed carry, which are known to be numerous (see above). Thus, if there were introductions of pumpkinseed into BC water bodies from sources in eastern Canada (perhaps through the aquarium trade), then the same water bodies that would support the pumpkinseed would also likely support the parasites that are associated with them. Treatment of the fish as well as the conditions in the transfer tanks would have a moderating effect on which would survive transport, however.

From the experience in the Great Lakes with the parasitic copepod, *Neoergasilus japonicus* it was shown that this parasite that was found on pumpkinseed was also able to spread easily to other fish in Lake Huron. The hosts for the parasite include cyprinids, percids, centrarchids, and ictalurids. Although this copepod has not been identified in BC, it is provided as an example that once a parasite is introduced into an area that it can sometimes spread to a wide range of fishes. Thus the risk that parasites that travel with pumpkinseed would be able to encounter susceptible organisms and suitable habitat and therefore establish themselves is moderate. Since there is no literature on the parasites of pumpkinseed in BC, the uncertainty is high.

As well, if there were to be an introduction of a parasite along with pumpkinseed into water bodies with existing populations of pumpkinseed, the risk of spread would be very high. The pumpkinseed is often found in high densities and the higher the density the faster the spread of parasites. As well, the parental care by the male pumpkinseed may increase the spread of the parasite to the offspring due to close contact of the juvenile fish. However, since pumpkinseed are not native to BC this is not a risk to native populations.

Table 4.6. Probability and uncertainty for the establishment of parasites, pathogens, and/or fellow travelers from introduced pumpkinseed in British Columbia.

	British Columbia	
Element	**Probability**	**Uncertainty**
Establishment	Moderate	High

4.5.2 The ecological and genetic impacts of pathogens, parasites, and fellow travelers on native ecosystems both locally and within the region.

Pumpkinseed can host at least 104 parasites species over its whole range (Hoffman 1967). It is not known which of these parasites are unique to the pumpkinseed which would have other hosts that are native to BC. Thus, the ecological impacts of these parasites is likely varied and difficult to pinpoint. However, since there has been no literature on disease outbreaks in BC from any of the parasites, the impact that they would have is likely low (because native species may sometimes be impacted by the parasites). The magnitude of the genetic impact of these parasites is low as native species of parasites may sometimes be impacted by the parasites.

Table 4.7. Estimated ecological and genetic consequences of the introduction of parasites, pathogens, or fellow travelers from introduced pumpkinseed populations.

	British Columbia	
Risk Component	**Impact**	**Uncertainty**
Ecological	Low	High
Genetic	Low	Very High

4.5.3 The aquatic risk potential for pathogen, parasite or fellow traveler.

The summary ranks for the probability of widespread establishment (Table 4.6) and the ecological and genetic consequences (Table 4.7) of parasites, pathogens, and/or fellow travelers of pumpkinseed are combined in Table 4.8 to obtain an overall risk ratings.

Table 4.8. Matrix for determining overall risk of pathogens, parasites, and/or fellow travelers of pumpkinseed. The ellipse represents both the ecological and genetic impacts.

Ecological or Genetic Consequences	Very High					
	High					
	Moderate					
	Low					
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of Widespread Establishment					

5. WALLEYE

5.1 Background and Biology

The walleye is a large member of the Percidae and is native to North America, east of the Continental Divide. Females are generally larger than males and can reach lengths in excess of 75 cm TL. Age at maturity is variable, and can range from 3-8 years for females and a year younger for males. Maximum age can be 14-18 years (Scott and Crossman 1973). Reproduction occurs in the spring when water temperatures rise above 5° C. Spawning takes place on rocky shorelines of lakes or cobble river beds. Extensive migrations and possibly homing to natal areas can occur before spawning (Wydoski and Whitney 2003). Fecundity increases with size and can range from 40 000 to 600 000 eggs per female (Colby et al. 1979). Across 85 North American lakes Baccanti and Colby (1996) found the median density of adult walleye was 15 fish/ha, with an interquartile range of 8-24 fish/ha. There was a slight trend towards lower densities in larger lakes.

Larval walleye hatch in 15-30 days and begin feeding a few days after hatching at a length of 12 mm. Larvae are initially planktonic, but settle in the littoral zone by early summer. Juvenile walleye occupy shoreline habitats, especially in the summer. Adult walleye tend to be close to shore during the night, and use deeper waters by day. In rivers, walleye prefer slower moving areas, especially where turbidity or staining reduces light penetration.

As larvae the diet is zooplankton, but they quickly switch to piscivory at lengths of 25-75mm TL. Juvenile and adult walleye diets are primarily fish, supplemented with insects or macroinvertebrates on occasion. In their native range yellow perch are a favoured prey item, although a wide variety of fishes can be taken (Forney 1974). Cannibalism of juveniles by adult fish has been observed (Chevalier 1973). Walleye can consume fish about one half of its length (Baldwin et al. 2003). In reservoirs in the western US, introduced walleye prey heavily on salmonids, including kokanee and rainbow trout (Baldwin et al. 2003; McMahon and Bennett 1996); predation on migrating salmon smolts in the Columbia River is also significant (Zimmerman 1999).

Young walleye are taken as prey by a variety of piscivorous fish in its native range. Fayram et al. (2005) note negative correlations between walleye survival and largemouth bass abundance, presumably due to direct predation impacts.

Walleye have relatively wide environmental tolerances. Their upper thermal limits may be in the range of 29-34° C, but they prefer temperatures of 20-24°C during the summer (Chu et al. 2004). Their presence in northern Canada demonstrates walleye can survive long winters and short growing seasons. Walleye can tolerate oxygen concentrations as low as 2 mg/L but prefer > 5 mg/L (reviewed by Hartman 2008). An analysis of stocking success and failures suggests walleye prefer slightly alkaline conditions (Bennett and MacArthur 1990). Stocking success was also more likely in larger (>400 ha) and deeper lakes. Walleye have specially adapted eyes that allow them to feed at low light levels. Consequently, optimal habitats for walleye are usually moderately turbid lakes or rivers (Scott and Crossman 1973; Chu et al. 2004; Lester et al. 2004).

Walleye can be infected with a wide variety of parasites (Scott and Crossman 1973). The tapeworm *Diphyllobothrium latum* has been found in walleye from the Prairies: this species can infect humans if uncooked flesh is consumed. No other specific risks associated with walleye parasites have been identified. Walleye are susceptible to *Viral hemorrhagic septicemia* (Grookock et al. 2007), an emerging disease that is spreading through many species in the Great Lakes region.

Walleye have expanded from their native range largely as a result by stocking by natural resource agencies, as well as some unauthorized introductions. Some of the first walleye translocations occurred in the 1870s when fish were captured in Vermont and released in the Sacramento River basin in California (Dill and Cordone 1997). In the Pacific Northwest, walleye appeared in reservoirs of the Columbia River in the 1960s, and within 2 decades had spread throughout the Columbia Basin, both upstream and downstream. The natural tendency of walleye to migrate great distances contributes to its capability to invade whole watersheds from a single point of introduction (McMahon and Bennett 1996; Wydoski and Whitney 2003; DePhilip et al. 2005).

5.2 Known distribution

The native distribution of walleye in Canada extends from western Quebec to the continental divide. They are also found in the Mackenzie Basin north to the Arctic Ocean, including the Peace and Liard Rivers of northeastern BC and Alberta. The native range also includes the Great Lakes states, and the Mississippi basin south to Alabama and Arkansas. Walleye have been introduced to the Atlantic coast states, as well as most of the Western states, and in particular, the Columbia River basin in Washington (Wydoski and Whitney 2003). The range expansion is largely due to deliberate transplants beginning in the late 1800s, as well as other introductions and spread. Although introduced on a number of occasions to California walleye have subsequently become extirpated in California (Dill and Cordone 1997).

In British Columbia walleye are native to the lower Peace River, and the Hay and Liard systems of northeastern BC (Figure 5.1). Two populations have been introduced near Fort St. John (McPhail, 2007; Hartman 2008). Walleye have spread from the Columbia River basin reservoirs in Washington where they were introduced (McMahon and Bennett 1996) into southeastern BC. Walleye have been recorded in the Columbia River mainstem below the Hugh Keeleyside Dam, the lower Kootenay River downstream of the Brilliant Dam, the Pend d'Oreille River, the Kettle River below Cascade falls and Christina Lake (Runciman and Leaf 2008; Table 8.1). Walleye are currently present in the Okanogan River in Washington State but have not reached the border.

Table 5.1. Counts of waterbodies containing introduced walleye, by region, in British Columbia, from Runciman and Leaf (2008).

	Region						
	Vancouver Island	Lower Mainland	Fraser	Thompson	Columbia	Arctic	Coast
Confirmed	0	0	0	0	3	2	0
Unconfirmed	0	0	0	0	2	0	0

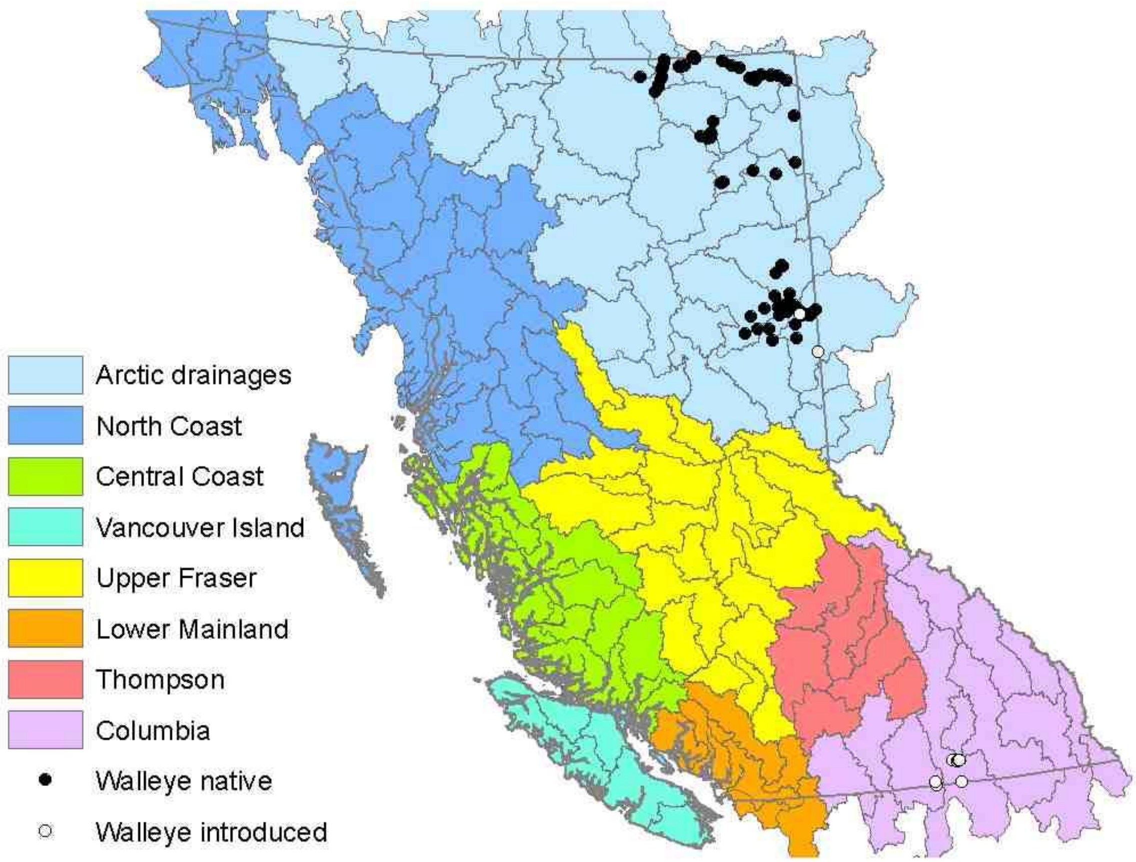


Figure 5.1. The known distribution of walleye in British Columbia. Data from Runciman and Leaf (2008).

5.3 Potential Distribution

The environmental niche model retained all environmental variables except slope based on the results of the initial model run. Model validation indicated a good predictive accuracy (0.803, $P<0.001$) based on its ability to predict BC occurrences for walleye. The ROC value quantifies the predictive quality of a model on a scale from 0.5 (no better than random prediction) to 1.0 (perfect prediction). Clearly, these predictions are based on climatic rather than aquatic variables which would be more desirable, but given the inability of the lake-specific model to predict this species in BC, it is the best available approach. Environmental niche modeling has been used successfully for the predicting the potential range of invasive aquatic species including several species of fish (Herborg et al., 2007; Iguchi et al., 2004). Our models predicted the highest mean suitability for the Thompson (86%) followed by the Upper Fraser, the Arctic and the Columbia areas (Table 5.2, Figure 5.2). The lowest level of environmental suitability is predicted for Vancouver Island (19%) and the Central Coast.

Table 5.2. Mean environmental suitability (0-100 scale) of each of the 8 analysis regions for walleye.

	Region							
	Vancouver Island	Lower Mainland	Fraser	Thompson	Columbia	Arctic	S. Coast	N. Coast
Suitability	19	53	82	86	70	72	33	48

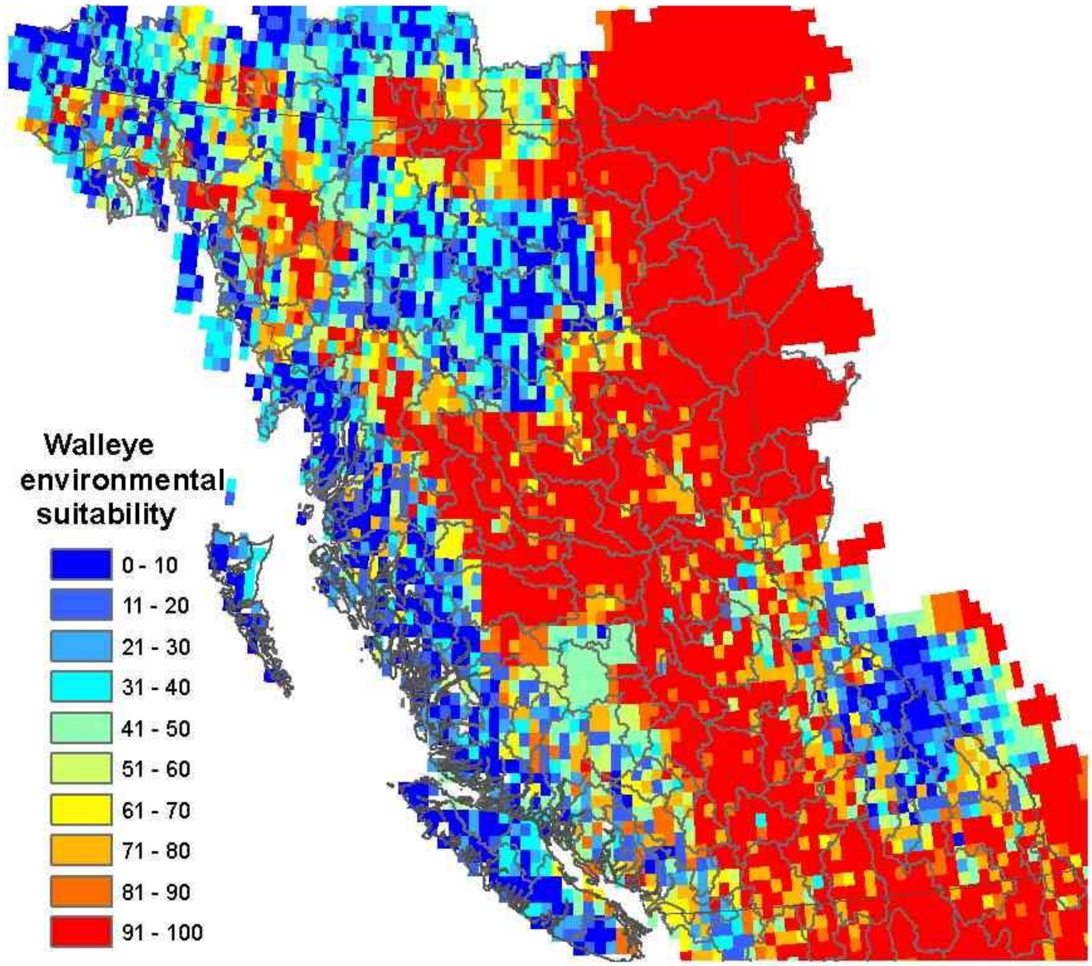


Figure 5.2. Predictions of environmental suitability for walleye in British Columbia. Areas with higher scores have environmental conditions more suitable for walleye populations.

5.4 Aquatic Organism Ecological and Genetic Risk Assessment

5.4.1 The probability of the organism arriving, colonizing and maintaining a population.

Walleye apparently do not colonize waterbodies after introduction as readily as yellow perch. Attempts to establish populations in California have not succeeded (Dill and Cordone 1997), and failures have been noted in BC and in the western US (Hartman 2008). In a North American survey of management agencies Bennett and McArthur (1990) found that 86% of agencies had attempted to establish walleye population using introductions, but the overall success rate was only 35%. In many cases agencies are forced to annually stock lakes because natural reproduction does not occur. Ellison and Franzin (1992) noted a 40% success rate for stocking fry and juveniles into Midwestern lakes and reservoirs. Greater rates of success were predicted to occur in larger lakes, and those with cover in the form of turbidity or depth. Lester et al. (2004) developed an environmental model that suggests intermediate water turbidity corresponding to a Secchi depth of about 2 m is optimal. Hartman (2008) listed a suite of factors he considered to be essential for the establishment of an introduced walleye population, of which some are:

- Large (>400 ha) mesotrophic lakes or turbid rivers or clear lakes with cover in the form of depth
- Clean spawning habitats sheltered from wind or currents
- Greater than 900°C degree-days during the summer
- An adequate abundance of zooplankton for larvae and forage fish for juveniles and adults
- Spring temperatures rising above 9°C

It is unclear whether the walleye currently found in the Canadian portions of Columbia basin rivers are self-sustaining populations or if they use these habitats on a seasonal basis (Wydoski and Whitney 2003).

5.4.2 The probability of spread.

Adult walleye can migrate great distances, and this enhances the species ability to spread from its initial point of introduction. While tagging studies tend to show most walleye have limited movement during the non-spawning period, there are often a few individuals that move long distances, some as great as 40 to > 200 km (Rawson 1957; Wydoski and Whitney 2003; DePhilip et al. 2005). After an initial introduction into Banks Lake (near the Grand Coulee dam) in Washington in the early 1960s walleye have subsequently spread downstream to the ocean within a few years. Upstream colonization has occurred in the Snake River basin, and into the Kettle and Okanogan Rivers

The spread of walleye is likely facilitated by the presence of suitable connecting waters, particularly large rivers with relatively slow moving currents and cover in the form of turbidity or depth. In southern British Columbia the presence of waterfalls or dams without passage facilities will limit upstream movements in some basins, while in others limited suitability of habitats in mountainous headwaters may inhibit spread.

Walleye may also spread as a result of deliberate human actions if it is considered desirable as a sports fish. To date, this does not appear to have occurred in British Columbia. It may be difficult for anglers to catch enough walleye for a successful introduction. As noted earlier the relatively large-scale stocking of walleye juveniles by agencies has had a relatively low success rate.

5.4.3 Final rating: widespread establishment of walleye.

Table 5.3. The probability of arrival, survival and reproduction, spread, and widespread establishment once arrived (WEOA) of the walleye in the eight regions of British Columbia with the associated uncertainties.

	Vancouver Island		Lower Mainland		Upper Fraser		Thompson		Columbia		Arctic Drainage		C & N Coast	
Element	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc
Arrival	L	M	M	H	L	H	M	H	H*	L	M*	H	VL	M
Surv. & Reprod.	M	M	H	M	VH	M	VH	M	H	M	M	M	M	M
Spread	M	M	M	M	H	M	H	L	H	M	M	M	VL	L
WEOA	M	M	H	M	H	M	H	M	H	L	M	M	L	L

Notes: Arrival: although already present in the Columbia a ranking was given for the Okanagan basin where walleye have been noted in the lower Okanogan River in Washington state. Ratings were also given for Arctic Region as the species natural range includes only a portion of the region.

5.4.4 The ecological impact on native ecosystems.

Although walleye can potentially compete with other species for common food resources, their main impact on native ecosystems is expected to be the result of predation for this largely piscivorous species. Within their native range walleye populations have long been known to strongly influence prey fish communities, particularly yellow perch, a preferred food species (Forney 1974). Walleye can significantly reduce perch populations, which can lead to predation on other species (Lyons and Magnuson 1987) or cannibalism (Chevalier 1973).

The impacts of walleye introductions in western North America were reviewed by McMahon and Bennett (1996). Although many introductions have not been successful (Dill and Cordone 1997), in the cases where walleye have become established, declines in native species have been observed. In some cases the depletion of the food base is extensive enough to cause walleye to decrease in size and decline in abundance (McMahon and Bennett 1996).

Introduced walleye have also become significant predators on native and managed salmonid populations in the western US. Declines in rainbow trout populations have been identified (Bell and Stevens 1984; McMahon and Bennett 1996) after walleye introduction. Yule et al. (2000) note that walleye were particularly effective predators of spring stockings of small (<127 mm) rainbow trout, and suggested that fall stocking of larger (>230 mm) fish would be required to establish a viable trout fishery in the presence of walleye. Marwitz and Hubert (1997) also found that walleye became effective predators of stocked trout fingerlings, and walleye body condition was positively correlated to the number of trout stocked in Wyoming reservoirs. Juvenile kokanee salmon and rainbow trout (133-208 mm FL) released from hatcheries were important components of the diet of walleye from Lake Roosevelt, Washington

(Baldwin et al. 2003). Walleye consumed about 10% of the hatchery fish during their first 41 d after release. Walleye also consumed migrating juvenile salmon in reservoirs of the Columbia River, although salmonids were not a preferred item compared to the feeding habits of northern Pikeminnow, the dominant native piscivore (Zimmerman 1999).

The introduction of walleye to waterbodies in British Columbia would likely impact native fish species. Walleye will only become abundant in habitats where environmental conditions are suitable, but if they do, they are very likely to deplete native soft-rayed fishes including salmonids (McMahon and Bennett 1996). Clear, oligotrophic lakes or rivers with small littoral zones are unlikely to support walleye. From the available evidence it is less clear that introduced walleye populations will cause the extirpation of native species. Although walleye consume migrating salmonids in large rivers, they are considered to be less significant than native piscivores. Based on modeling results for the Columbia River walleye were estimated to be responsible for only a small loss in productivity of salmon populations (Harvey and Kareiva 2005).

5.4.5 Genetic impacts on local self-sustaining stocks or populations.

The only other native member of the Percidae is the yellow perch which has native populations in the Peace, Liard and Hay River basins of northeastern BC. Wiggins et al. (1983) experimentally crossed walleye and yellow perch and found that fertilization was successful but the eggs failed to hatch. Walleye are known to hybridize with the sauger (*Sander canadensis*) which has a similar native range to the walleye but are not found in BC.

Introduced walleye in the Columbia drainages of southern BC (which likely have origins in the Midwestern US) are unlikely to interbreed with native walleye of the Mackenzie River basin in northeastern BC unless there is a dramatic escalation of unauthorized interbasin transfers from south to north in the province. Thus the risk of outbreeding depression from the matings of non-native and native populations seems remote.

5.4.6 Final rating: ecological and genetic consequences.

Table 5.4. Final ratings of ecological and genetic consequences to aquatic biota from introductions of walleye.

	British Columbia	
Element	**Magnitude**	**Uncertainty**
Ecological Consequence	High	Moderate
Genetic Consequence	Very Low	Low

5.4.7 The aquatic risk potential for walleye.

The summary ranks for the probability of establishment (introduction, survival, and reproduction) and the ecological and genetic consequences are combined in Tables 5.5 and 5.6.

Table 5.5. Matrix for determining overall ecological risk for walleye.

Ecological consequences	Very High					
	High		CC,NC	VI,AR	LM,UF,TH,CO	
	Medium					
	Low					
	Very Low					
		Very Low	Low	Moderate	High	Very High
	Probability of widespread establishment					

Table 5.6. Matrix for determining overall genetic risk for walleye.

Genetic consequences	Very High					
	High					
	Medium					
	Low					
	Very Low		CC,NC	VI,AR	LM,UF,TH,CO	
		Very Low	Low	Moderate	High	Very High
	Probability of widespread establishment					

5.5 Pathogen, Parasite or Fellow Traveler Ecological and Genetic Risk Assessment

5.5.1 The probability that a pathogen, parasite or fellow traveler may be introduced along with the potential invasive species and become established.

Walleye introductions in BC will likely result from movements of fish from established populations or illegal introductions. These established populations are native to northeastern BC, or have been introduced to the Columbia basin in Washington State. Fish illegally introduced are unlikely to be screened or treated for disease. Therefore any parasites or pathogens on or in these fish will likely accompany their hosts.

Since the walleye can live in a wide range of environmental conditions, it might be expected that a hypothetical associated organism native to walleye will also be able to survive where the walleye can. The impact of a parasite may be a function of its prevalence (the proportion of fish infected) at the time of the introduction and the number of fish in the introduction. The survival of some parasite species will depend on the suitability of available secondary hosts. The survival of new exotic parasites such as those arriving in the Great Lakes is less clear.

Table 5.7. Ratings for the probability of establishment of pathogens, parasites and/or fellow travelers of walleye in BC and the associated uncertainty.

	British Columbia	
Element	**Probability**	**Uncertainty**
Establishment	High	High

5.5.2 The ecological and genetic impacts of a pathogen, parasite or fellow traveler on native species and ecosystems.

Walleye were introduced to the western US over 50 years ago and there has been no documentation of unique diseases or parasites associated with those populations (Hartman 2008). However, it is unclear if this issue has been investigated rigorously. No information is available on the genetic risks of traveler organisms.

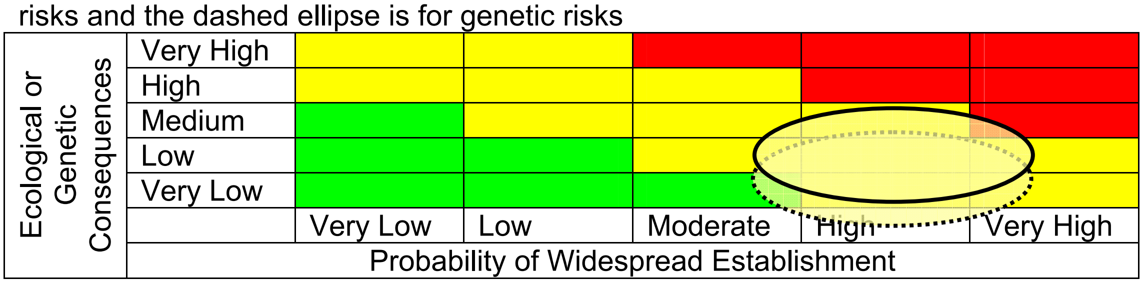
Table 5.8. Ecological and genetic consequences of pathogens, parasites or fellow travelers of introduced walleye in BC.

	British Columbia	
Risk Component	**Impact**	**Uncertainty**
Ecological	Low	Very High
Genetic	Very Low	Very High

5.5.3 The aquatic risk potential for pathogen, parasite or fellow traveler.

The summary ranks for the probability of establishment and the ecological and genetic consequences are combined in the following table to obtain an overall risk rating for pathogens, parasites, or fellow travelers.

Table 5.9: Matrix for determining overall risk for parasite. The solid ellipse represents ecological risks and the dashed ellipse is for genetic risks



6. CONCLUSIONS

Although native to much of North America, the northern pike, pumpkinseed, and walleye have been extensively introduced outside of their native ranges, particularly in the west. The pumpkinseed is perhaps best considered to be a nuisance species as it has generates little interest for anglers, but can have indirect impacts on aquatic communities, particularly in small, warm lakes. The northern pike and walleye are desirable fish for angling, which has lead to both authorized and illegal introductions. For both species there are many examples where these species have had considerable impact on native fish communities through predation. The northern pike, in particular, can have devastating effects on native fish in lakes with extensive littoral areas. There are very uncertain risks resulting from parasite introductions associated with these species. Consequently, in this risk analysis all three species received high risk ratings, especially for small lakes in the southern part of BC. Once introduced, these species are very difficult to eliminate, suggesting proactive measures are needed if their spread is deemed undesirable.

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