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Biological Risk Assessment for Yellow Perch (*Perca flavescens*) in British Columbia

Évaluation du risque biologique posé par la perchaude (*Perca flavescens*) en Colombie-Britannique

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ABSTRACT

We performed a qualitative risk assessment of the ecological and genetic impacts of the non-native yellow perch (*Perca flavescens*), and their parasites, pathogens and fellow travelers to native ecosystems in British Columbia. The yellow perch is widely distributed in North America, and has been introduced into southern British Columbia and also in the northeastern part of the province. In BC it has been spread mainly by illegal introduction. The yellow perch is an adaptable and prolific species; when introduced into small lakes, yellow perch can have severe impacts on native fish species, largely as a result of competition for food. Its impact in larger lakes is less severe, though less information is available. For most regions of BC the probability of becoming widely established once arrived was considered high or very high. The magnitude of the ecological impact in small water bodies was considered very high, and moderate in large lakes and rivers. Because there are no members of the Perch family native to BC, the potential genetic impact of introduced yellow perch to native biota is likely low. There were few published papers to inform our assessment of the potential impact of parasites, pathogens, and fellow travelers to native ecosystems in BC, however the risks were considered low.

RÉSUMÉ

Nous avons procédé à une évaluation qualitative du risque posé par les impacts écologiques et génétiques de la perchaude (*Perca flavescens*) non indigène ainsi que de ses parasites, de ses agents pathogènes et de ses compagnons de route sur l'écosystème de la Colombie-Britannique. La perchaude, qui a une aire de répartition étendue en Amérique du Nord, a été introduite dans le sud et le nord-est de la Colombie-Britannique. En C.-B., l'espèce s'est propagée principalement en raison d'introductions illégales. La perchaude est une espèce qui s'adapte facilement à un nouvel environnement et qui prolifère rapidement; lorsqu'elle est introduite dans de petits lacs, la perchaude peut avoir d'importants impacts sur les espèces de poissons indigènes, en grande partie en raison de la compétition pour la nourriture. Son impact dans les plus grands lacs est moins important, bien que moins d'information soit disponible à ce sujet. Pour la plupart des régions de la C.-B., la probabilité que l'espèce s'établisse à grande échelle une fois arrivée est considérée comme élevée ou très élevée. L'importance de l'impact écologique dans les petits plans d'eau est considérée comme très élevée, et comme modérée dans les grands lacs et les rivières. Étant donné qu'on ne trouve pas de membres indigènes de la famille des perches en C.-B., le potentiel d'impact génétique causé par l'introduction de la perchaude sur le biote indigène est vraisemblablement faible. Peu d'études publiées étaient disponibles pour documenter notre évaluation de l'impact potentiel causé par les parasites, les agents pathogènes et les compagnons de route sur l'écosystème de la C.-B.; cependant, le risque est considéré comme faible.

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 2007).

In British Columbia most agency-sponsored introductions have been salmonids for the purpose of recreation and commercial fishing. Brook char (*Salvelinus fontinalus*) and brown trout (*Salmo trutta*) 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 2003).

This document considers the risk to aquatic communities in British Columbia posed by the potential expansion in range, largely by unauthorized introductions, of yellow perch (*Perca flavescens).* This species is native to North America, has been introduced and is established at numerous locations in the border states (Washington, Idaho, Montana) and Alberta. Yellow perch is among the most commonly introduced species in the United States (Rahel 2000).

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. 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 2003).

A biological synopsis has been commissioned (Brown et al. 2008), which provides information of the species natural history, distribution, and documented instances where it has been shown to impact aquatic communities as an invasive species. A supporting document (Runciman and Leaf 2008) details current known occurrences of each species in BC.

Risk ratings for yellow perch 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.

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

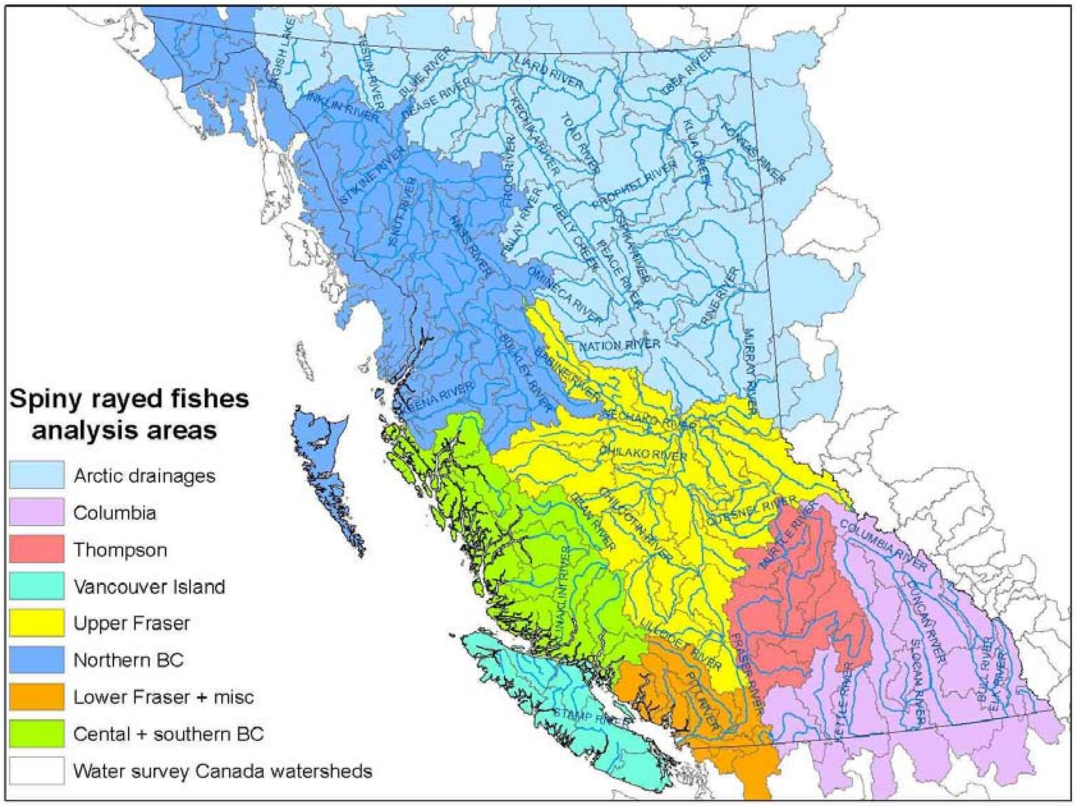


Figure 1.1. The eight analysis regions for use in the risk assessment process. The Arctic region includes headwater tributaries of both the Mackenzie and Yukon Rivers. The lower mainland region includes small transboundary basins and the Sunshine Coast/Whistler area.

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. 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 1.3). If the species was already present within a region a risk rating was not needed and an ‘A’ was entered in the tables.

Table 1.3. 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. For yellow perch we used environmental niche modeling to evaluate the suitability of lakes in each region. Modelling results (expressed on a 0-100 scale) were used in the rating scheme (Table 1.4). Details of the environmental niche modeling 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 1.4. Constructed scale for survival and reproduction based on habitat suitability or environmental niche modeling.

Element Rank	Environmental Niche Score (0-100)
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. Human vectors are assessed based on the human population size and the number of visitations of sport fishers to the region. The recent pattern of introductions also influences this evaluation (Table 1.5).

Table 1.5. 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. This was based on an expert assessment of the probability of survival, reproduction and spread, and was guided by the definitions provided in Table 1.6.

Table 1.6. 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 1.7 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 1.7. 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 1.8). We have taken an evidenced-based approach and assess risk by reviewing empirical information.

Table 1.8. 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 1.9). 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 regions.

Table 1.9. Matrix for determining overall risk, where green indicates low risk, yellow indicates moderate risk, and the red region represents high risk situations (from Mandrak and Cudmore 2006).

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

2. Habitat Modeling

The potential occurrence of yellow perch 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).

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. Yellow Perch Background and Biology

The yellow perch is a small to moderate-sized member of the Percidae and is often distinguished by its yellow or brassy colour and darker vertical stripes on its body. Adult size is highly variable, being as little as 10-15 cm TL in stunted populations, to 25-30 cm in others (Scott and Crossman 1973). The age at maturity in females is 2-4 years, and is one year less for males. Reproduction occurs in the spring when water temperatures rise above 7° C. Aquatic macrophytes and submerged terrestrial vegetation or woody debris in the littoral zone are preferred spawning substrates, although other substrates are used. Yellow perch are very fecund, and can produce 20-150 thousand eggs. Small (5 mm) larvae appear 1-4 weeks after spawning (McPhail 2007).

Yellow perch inhabit both small and large lakes, slow moving rivers, and even brackish waters. Adults are generally associated with the littoral zone, although they occupy deeper waters in winter and also in summer when surface waters are too warm. Abundances are highest in lakes with clear water and abundant macrophytes (Purchase et al. 2005). Movements are generally limited, as adults appear to have home ranges. Larval yellow perch are initially limnetic, but move to inshore areas at 2-3cm TL, where vegetation and debris are used as cover.

As larvae, yellow perch initially consume zooplankton, but the diet switches to benthic invertebrates as juveniles settle in the littoral zone (Fulford et al. 2006). The diet of adult fish is diverse, and includes benthic invertebrates, zooplankton and small fishes (McIntyre et al. 2006). Within-cohort competition for food resources can be intense and can lead to the stunting that is observed in small lakes. Cannibalism by older age classes has been observed and had been inferred to play a role in the determination of year-class strength (Sanderson et al. 1999).

Perch populations can be shaped by the combined effects of predation on them, and intra-specific competition (Pierce et al. 2006). Yellow perch populations are often considered forage fish as they are a favored diet item for walleye, bass and other piscivorous species. Increased predation on yellow perch can cause population declines, but lead to increased growth rates and larger ages at maturity (Pierce et al. 2006). Lippert et al. (2007) noted that the risk of predation caused by the presence of smallmouth bass resulted in a change in foraging behaviour in juvenile perch. In the absence of significant predation pressure stunting can occur as a consequence of competition for food by dense perch populations (Heath and Roff 1987).

As evidenced by their broad distribution in North America, yellow perch have wide environmental tolerances. Upper thermal limits of 25-30 ºC have been proposed, and their presence in the northern parts of the Prairie provinces suggests they can persist in conditions of long winters and relatively short and cool growing seasons, although growth and productivity are probably low. Yellow perch are tolerant of brackish water to 15-20 ppt, relatively low levels of dissolved oxygen (to 5 mg/L), and high levels of acidity (pH < 5). Their diverse diet and lack of specific habitats for spawning likely contribute to their adaptability to a variety of lakes and rivers (Scott and Crossman 1973).

Yellow perch can be infected with a wide variety of parasites (Scott and Crossman 1973). Of particular note is the broad tapeworm (*Diphyllogothrium*) that can be transmitted to humans through the ingestion of raw flesh. The non-native microsporidian *Heterosporis sp*. has recently been discovered in yellow perch in the Great Lakes area, which may have spread from aquarium species. This parasite has no effect on humans but does degrade the quality of fish flesh. Experimentally, it has been found to infect salmonid species and may be spreading in the Great Lakes region. Yellow perch are also a host for the larval stages of freshwater clams. Szalai and Dick (1991) note that the nematode *Raphidascaris acus* can cause a decline in condition of infected yellow perch and higher rates of predation by northern pike.

Another exotic 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 parasites are unknown, although they appeared to reduce growth in some species of fish.

The expansion of the range of yellow perch in North America is largely the result of deliberate human introductions by resource agencies or by unauthorized introductions. Because of the wide environmental tolerances many of these introductions have been successful; perch are found in 46 of the 48 contiguous states (Rahel 2000). In California, Moyle (2002) describes a number of populations that were introduced but eventually disappeared. For some of these it was speculated to be the result of increased turbidity as a result of land use practices (Dill and Cordone 1997). Once introduced, yellow perch can disperse downstream and become established in additional areas. Dill and Cordone (1997) describe the spread of yellow perch from an upstream reservoir to the mainstem Klamath River between 1946 and 1951. As adult perch are not migratory, downstream spread may be the result of the drift of larvae or small juveniles, and the establishment of populations may depend on the availability of suitable slow moving habitats downstream from the source population. Upstream movements, presumably by adults, have been observed in cases where conditions permit.

4. Known Distribution

The native distribution extends through most of central and eastern Canada, with the exception of Cape Breton Island, Prince Edward Island, and Newfoundland and Labrador. The native range also includes New England, the Midwestern States, and the east coast states as far south as Florida (Scott and Crossman 1973). The present-day range includes most of the

Western states, and in particular the Columbia River basin in northern Washington, and waters surrounding Puget Sound (Wydoski and Whitney 2003). The range expansion is largely due to a deliberate transplants beginning in the late 1800s, furthered by agency-led and unauthorized introductions (Dill and Cordone 1997).

In British Columbia yellow perch have been confirmed in 78 waterbodies in 5 of our 8 regions (Table 4.1, Figure 4.1). Perch are native to headwaters of the Peace basin (Nelson and Paetz 1992), but their natural occurrence in northeastern BC waters is unclear (McPhail 2007). Their range in the Peace area has expanded as the result of deliberate introductions, some by agency staff in the 1970s and 1980s (Runciman and Leaf 2008).

The majority of introduced populations in BC are found in the Columbia basin. Many of these are likely the result of upstream movements of fish that were introduced into reservoirs and lakes in Washington State. Yellow perch were first observed in these transboundary areas in the 1950s. Runciman and Leaf (2008) note a number of additional observations in isolated lakes that are likely the result of unauthorized introductions. Headwater introductions were likely the source of yellow perch in Okanagan and Skaha Lakes, which are isolated from the Columbia Basin by Okanagan Falls. There is no record of yellow perch in the upper Fraser basin or in the coastal regions.

Unauthorized introductions into the Vancouver Island, Lower Mainland, and Thompson Regions are all relatively recent (<15 yrs), as are sightings in isolated lakes and streams in the Columbia basin (Runciman and Leaf 2008).

Table 4.1: Counts of waterbodies containing introduced yellow perch, by region, in British Columbia, from Runciman and Leaf (2008). The "at risk" row are for waterbodies connected to those containing introduced yellow perch populations.

	Region						
Category	Vancouver Island	Lower Mainland	Fraser	Thompson	Columbia	Arctic	N&C Coast
Confirmed	8	1	0	12	48	9	0
Unconfirmed	1	0	0	0	2	1	0
At risk	11	0	0	4	21	2	0

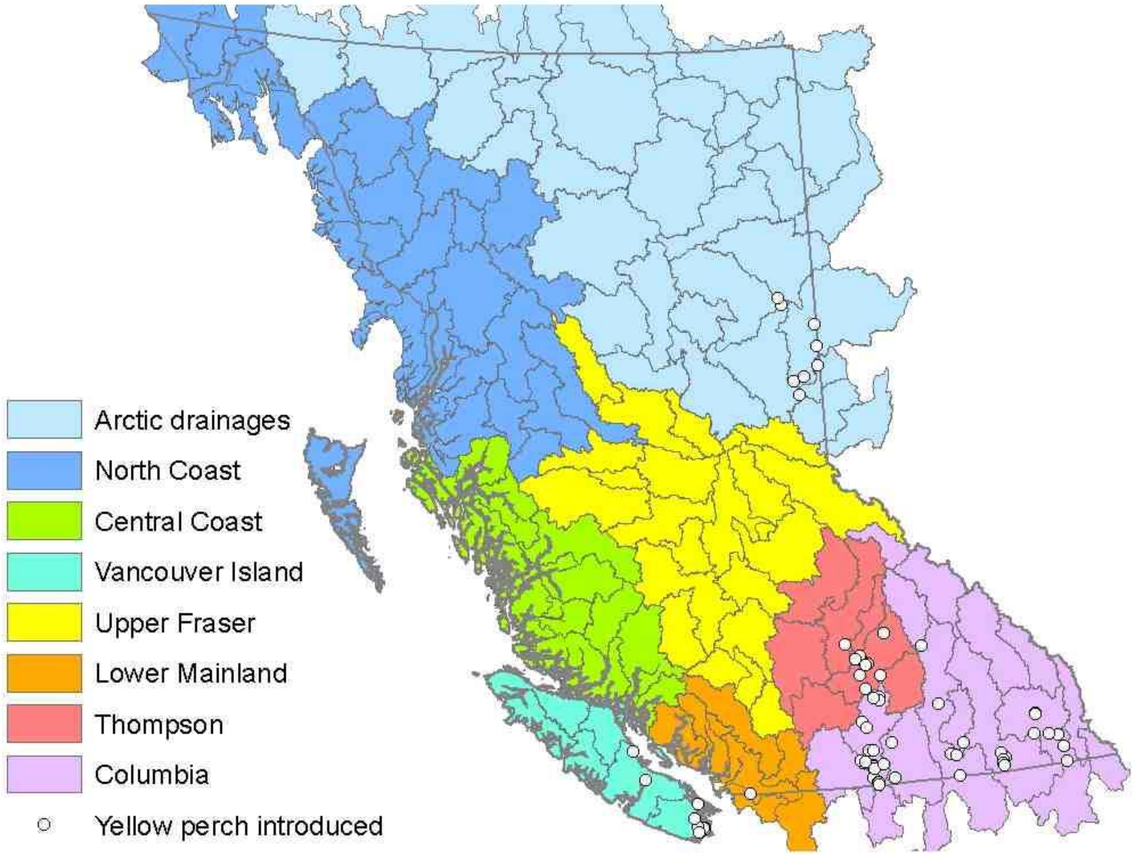


Figure 4.1: Distribution of known (confirmed) occurrences of yellow perch in British Columbia (data from Runciman and Leaf 2008).

5. Potential Distribution

The final prediction of yellow perch included all of the environmental layers in Table 2.1. Model validation indicates a high model accuracy (0.850, $P < 0.0001$), where a 0.50 is a no better than random, and a 1.0 is a perfect prediction. The validation is based on the models ability to predict occurrences of yellow perch in BC as suitable. The majority of unsuitable areas are predicted for northern BC, Vancouver and Queen Charlotte Islands and coastal areas of the Central coast. The highest predicted suitability was in the Thompson and Upper Fraser watersheds followed by the Columbia. The lowest environmental suitability was for Vancouver Island although the southeastern part of Vancouver Island was predicted to be more suitable (Figure 5.1).

Table 5.1. Mean environmental suitability (0-100 scale) for each of the 8 analysis regions for perch.

	Region							
	Vancouver Island	Lower Mainland	Upper Fraser	Thompson	Columbia	Arctic Drainage	Central Coast	North Coast
Suitability	8	45	79	79	70	39	29	39

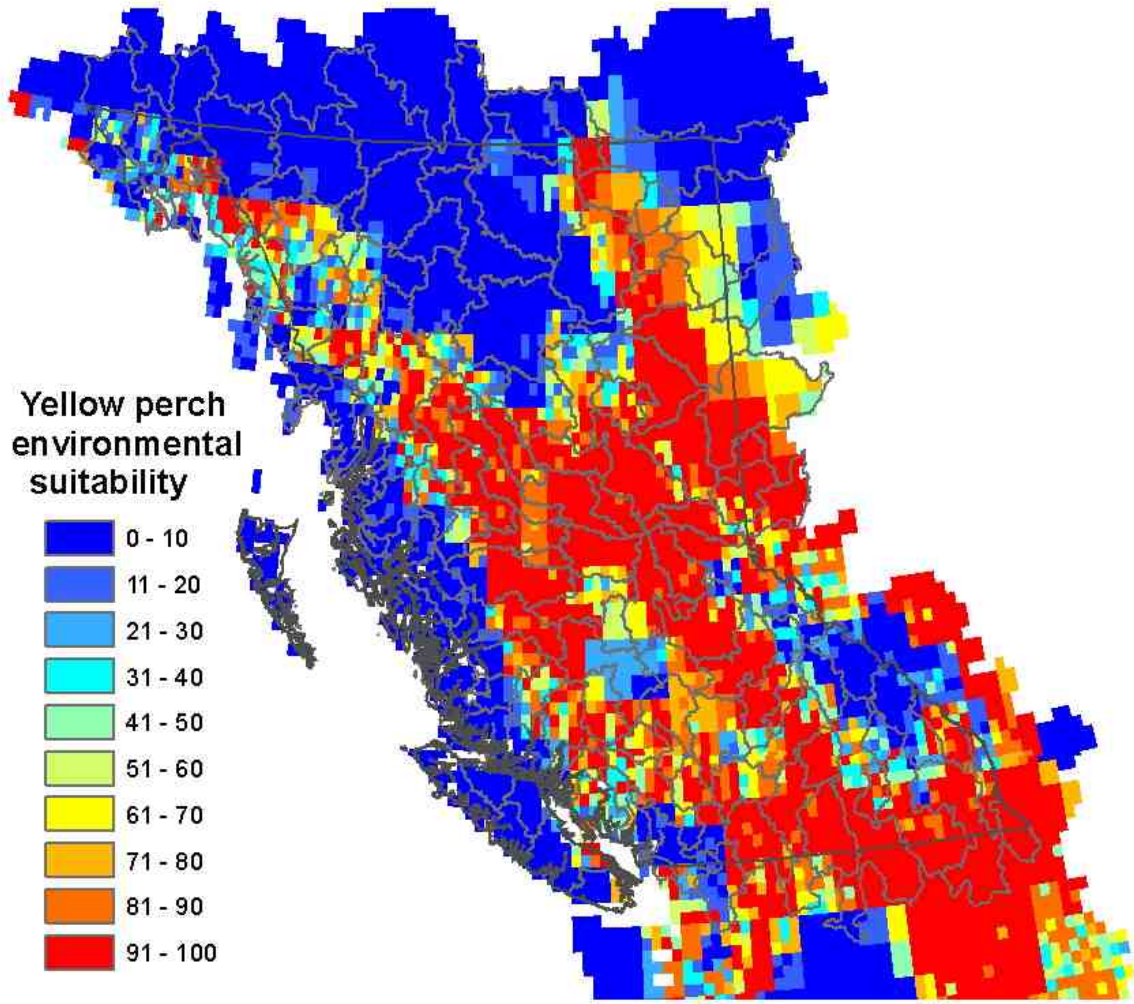


Figure 5.1. Environmental niche modeling results for the yellow perch in British Columbia. Areas with higher scores have environmental conditions predicted to be more suitable for yellow perch populations.

6. Aquatic Organism Ecological and Genetic Risk Assessment

6.1 The probability of the organism arriving and becoming established.

The range of yellow perch has expanded mainly by deliberate human introductions, with an important secondary vector of spread via movements to connected waterways, when suitable conditions occur. In British Columbia yellow perch have arrived and have been observed in 5 of our 8 regions. Because the species has already arrived in these regions, a risk rating is not needed. The absence of yellow perch in the two coastal regions likely reflects small human populations, and possibly a preference for angling opportunities for existing species. A lower risk rating is applied to these areas.

Yellow perch introductions are usually successful, which has undoubtedly contributed to its widespread use as a warmwater forage or game species in the western US. Other than some dwindling populations noted by Moyle (2002) in California and some apparent extirpations in the Gulf states, records of failed introductions are difficult to find although introduced yellow perch populations have been decimated when walleye are also introduced (McMahon and Bennett 1996). Yellow perch have wide environmental tolerances and are not specialized feeders. Their ultimate abundance once established will depend on lake productivity, littoral zone development and predator populations. Thus the probability that a population will become established once introduced is high. This rating best applies to small lakes, where the chance of establishment from an unauthorized introduction is probably higher than would be the case in a large lake or river.

6.2 The probability of spread.

Although yellow perch are not noted for strong swimming capability or propensity to migrate, experience in BC and elsewhere indicates that in time, perch will spread to adjacent water bodies if conditions are suitable. Dill and Cordone (1976) note that yellow perch colonized placer ponds and backwaters of the Klamath River from a source population that was illegally introduced into an upstream reservoir. Downstream spread could occur by passive larval drift or movements of larger fish; presumed upstream movements and colonizations by larger fish have been observed in the Okanogan and Columbia River systems (McPhail 2007).

Established populations can also be used as sources of fish for people attempting to conduct unauthorized introductions in unconnected lakes. The probability of this occurring is difficult to predict, as it could be carried out at a large scale by relatively few individuals. Runciman and Leaf (2008) summarize information on the patterns of unauthorized introductions in BC.

6.3 Final rating: widespread establishment of yellow perch.

Table 6.1. The probability of arrival, survival and reproduction, spread, and widespread establishment once arrived (WEOA) of the yellow perch in the eight regions of British Columbia with the associated uncertainties. An “A” in the first row indicates that perch are already present in the region.

	Vancouver Island		Lower Mainland		Fraser		Thompson		Columbia		Arctic		C & N Coast	
Element	Rank	Un	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc	Rank	Unc
Arrival	A		A		H	M	A		A		A		M	M
Surv. & Repr.	M	M	H	M	H	M	H	M	H	M	M	M	M	M
Spread	H	L	H	M	H	H	VH	L	H	L	M	M	L	M
WEOA	H	M	H	M	H	H	VH	M	H	M	M	M	M	M

6.4 Estimate the ecological impact on native ecosystems locally and within the region.

Although much is known about the ecological niche of yellow perch in its natural range, its impact on native species after its introduction as a non-indigenous species has not been well studied. Consequently, the risks to native species must be largely inferred from observations of its habits in its native range, and are thus correspondingly uncertain.

Yellow perch are very prolific, and in small lakes that lack predators populations can build to very high levels. Growth rates are reduced in these cases, and stunted populations are common (Purchase et al. 2005). Because growth is negatively related to density, this infers that perch populations can significantly reduce their food resources within their foraging areas (Post and Cucin 1984). Planktivores in small lakes can significantly reduce zooplankton populations, causing an increase in phytoplankton and a decrease in water clarity (Johnson and Kitchell 1996).

The food being consumed by yellow perch seems to depend on the conditions of the lake. In shallow, eutrophic lakes in South Dakota, perch diets were a mixture of zooplankton and benthos, with fish being of little importance (Brown and St. Sauver 2002). However, piscivory, including cannibalism by juvenile perch on YOY conspecifics has been observed in more oligotrophic situations (Post and Evans 1989; McIntyre et al. 2006).

Salmonids generally fair poorly in competitive interactions with yellow perch. In small pothole lakes in Michigan, Eschmeyer (1938) found that the survival and growth of stocked trout and char was very low in lakes with existing yellow perch populations. Fraser (1978) observed a decrease in the growth and survival of char and trout in an Ontario lake after yellow perch were introduced, and attributed this to competition for food. After the perch introduction salmonids were forced to forage on smaller food items, causing a drop in productivity. Perch growth decreased dramatically a few years after introduction and the population became stunted. Similar negative interactions in small lakes were inferred by Smith (1935), Gunn et al. (1987) and Flick and Webster (1992). This situation has apparently occurred in small lakes in BC where yellow perch have been introduced.

The impact of yellow perch introductions into larger lakes or reservoirs is less clear, and may be related to the existence of predators. Yellow perch population dynamics are strongly affected by the presence of predatory fish such as bass and walleye that will tolerate spiny-rayed fish as prey. In lakes with these species perch populations are reduced in number, but grow quicker to larger adult sizes (Pierce et al. 2006).

Shrader (2000) documented the use of zooplankton by an expanding yellow perch population in an Oregon reservoir, and suggested that perch grazing was causing the zooplankton to become smaller, and potentially less suitable for other species. The subsequent expansion of the perch population has lead to the decline in the quality of a stocked rainbow trout fishery, and calls for perch eradication measures. Similar concerns were expressed by Johnson and Koski (2005) for a large reservoir in Colorado, where alteration of the zooplankton community by a rapidly expanding perch population has the potential to impact kokanee salmon.

Yellow perch were introduced into Lake Washington years ago, which is also an important sockeye salmon nursery lake. The perch population forms only a small (<2%) of the total fish biomass in the lake (Eggers et al. 1978). The diet of larval and juvenile yellow perch is pelagic plankton, but shifts to benthic organisms (mainly large sculpins) for the adults. Diet studies have not identified salmon or trout as a significant food source (Bartoo 1977; McIntyre et al. 2006). Though regulated, Lake Washington has a more developed littoral zone (including macrophyte beds) than Western reservoirs and piscivorous fish populations, which may contribute to the increased use of nearshore areas by yellow perch.

In a study of the effects of non-native fish on coho salmon in small lakes in western Washington, Bonar et al. (2005) examined over 800 yellow perch stomachs and found that the perch diet was dominated by benthic invertebrates (>90% by weight), with only one coho salmon being recorded. Largemouth bass were the most significant predators of native salmonid populations, and probably also played a role in limiting the perch population.

Yellow perch were observed to consume chinook salmon smolts when the salmon were migrating from Lake Sammamish, Washington, however, perch diets before and after the migration were dominated by invertebrates (Footen 2003). These results suggest the effects of yellow perch on salmon populations may be localized and specific to the salmon species present as well as their migrations.

The degree to which native predators of western North America can impact introduced yellow perch populations is unclear. Savitz and Bardygula-Nonn (1997) showed that large piscivorous Pacific salmon from the Great Lakes selected against juvenile yellow perch, and speculated that perch spines made these fish difficult for the salmon to ingest. In Columbia River reservoirs yellow perch were found in the stomachs of introduced smallmouth bass, but were apparently not predated on by native northern pikeminnow (*Ptycoheilus oregonensis*; Zimmerman 1999). Johnson and Koski (2005) speculate that the high thermal tolerances of yellow perch may allow them to escape predation by lake trout in the summer, the latter being restricted to colder waters. These observations raise the possibility that native fishes in BC may not be effective predators on yellow perch.

In summary, there are sufficient observations to suggest that the introduction of yellow perch to small water bodies will have significant effects on local biota, particularly salmonids, and has a high likelihood of preventing salmonid stocking programs from being successful. For large and very large water bodies there is less evidence and more variation in the significance of introduced yellow perch populations to the lake ecosystem. Although the biota that would be affected by perch populations will vary among regions, we have no information to predict differences among the regions in their impact.

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

The only other native member of the Percidae is walleye 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. Inviable hybrids were also produced from crosses of yellow perch and muskellunge (*E. masquionogy*; Dabrowski et al. 2000). It would appear unlikely that yellow perch would interbreed with other native species and produce viable hybrids.

6.6 Final rating: ecological and genetic consequences.

Table 6.2. Magnitude of the ecological and genetic consequences and the related uncertainties for introduced yellow perch in British Columbia.

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

Notes: The high rating for small lakes is based on the observations of impacts on salmonids in many (but not all) cases. These impacts could include the near extirpation of some local species. Large lakes are given a moderate rating as it appears that introductions could cause reductions in local populations in some cases, but not in others. There is much more uncertainty in the large lake case. No information is available to evaluate region-specific impacts.

6.7 Overall risk rating.

The summary ranks for the probability of establishment (introduction, survival, and reproduction) and the ecological and genetic consequences are combined in the following table to obtain an overall risk rating. Tables 6.1 and 6.2 are combined in the following tables to obtain an overall risk rating.

Table 6.3: Matrix for determining overall ecological risk, where green indicates low risk, yellow indicates moderate risk, and the red region represent the conditions for a high risk designation, with regions of similar risk grouped together. Dashed lines are for small water bodies, solid lines are for large lakes and rivers.

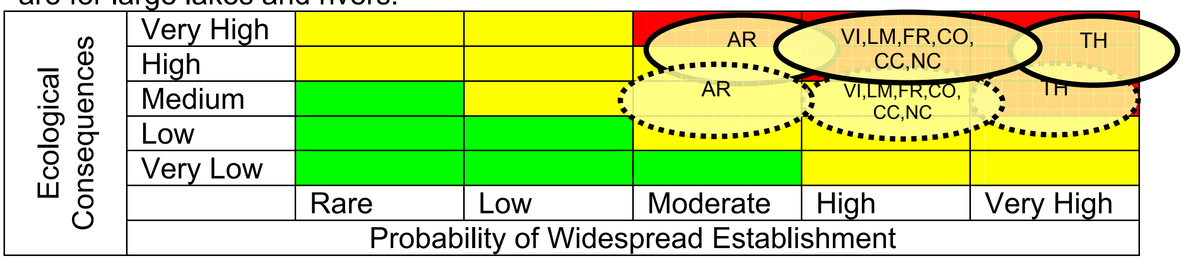
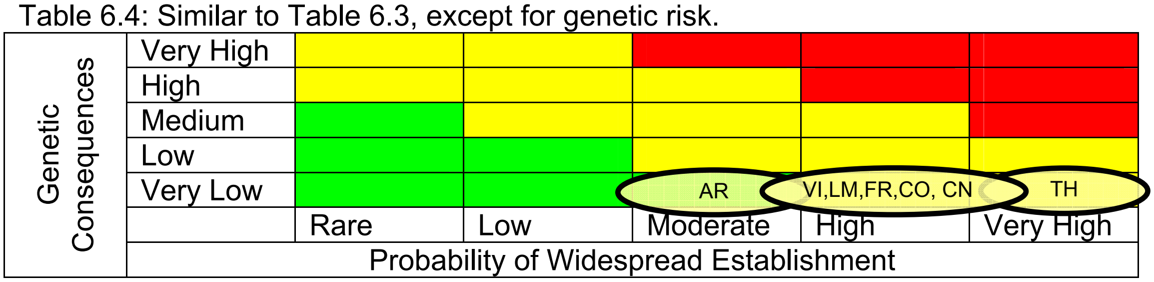


Table 6.4: Similar to Table 6.3, except for genetic risk.



7. Pathogen, Parasite or Fellow Traveler Ecological and Genetic Risk Assessment

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

Yellow perch introductions in BC will likely result from movements of fish from established populations. The established populations were most probably derived from nearby populations from Alberta (for northeastern BC) and Washington State. Fish used for illegal introductions are unlikely to be treated for parasites or diseases, so it is very likely that those organisms will be successfully introduced along with the yellow perch.

Since the yellow perch can live in a wide range of environmental conditions, it might be expected that a hypothetical associated organism native to perch will also be able to survive where the perch can. The survival of exotic parasites is less clear.

Table 7.1. Probability and uncertainty for the establishment of parasites, pathogens, and/or fellow travelers from introduced yellow perch in British Columbia.

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

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

Yellow perch were introduced to the western US over 100 years ago and there has been no documentation of unique diseases or parasites associated with those populations (Brown et al. 2008). However, this may be partially due to the absence of directed investigations. Novel parasites such as *Heterosporis* may infect yellow perch, but is not known if the introduction of yellow perch populations within BC will aid in the spread of these pathogens.

No information is available on the genetic risks of traveler organisms.

Table 7.2 Estimated consequences of the consequences of the introduction of parasites or pathogens from introduced yellow perch populations.

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

7.3 Overall risk rating for pathogens, parasites or fellow travelers.

The summary ranks for the probability of establishment and the ecological and genetic consequences are combined in Table 7.3 to obtain an overall risk rating for pathogens, parasites, or fellow travelers.

Table 7.3: Matrix for determining overall risk for parasites and fellow travelers. The ellipse represents the overall risk associated with the combined effects of establishment and genetic and ecological consequences.

Ecological or genetic consequences	Very High					
	High					
	Medium					
	Low				All regions	
	Very Low					
		Rare	Low	Moderate	High	Very High
	Probability of widespread establishment					

8. Conclusions

Yellow perch represent a significant risk to native biota in British Columbia. With wide environmental tolerances, high reproductive potential, and the potential to spread by natural and human activities there is a significant likelihood of yellow perch becoming widespread in British Columbia, as they have become in the Pacific Northwest of the United States. Yellow perch can have large impacts on native biota in small lakes and thus were considered to be of high risk. Their impact in large lakes may be lower as they are usually limited to the littoral zone, although localized effects may occur. There is considerable uncertainty about their impact in large waterbodies.

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