A Biological Synopsis of Yellow Perch (*Perca flavescens*)

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This synopsis reviews biological information on the yellow perch in support of a risk assessment evaluating the impacts of its expansion into non-native areas of Canada. Yellow perch is a small member of the perch family and is native to northern North America, east of the continental divide. Its range has expanded through introductions for sport fishing, or as forage fish for other species. Yellow perch have very wide habitat preferences and are especially prolific in small lakes. They are usually found in the littoral zone where they feed on benthic invertebrates, although in some cases they can be zooplanktivores in larger lakes. Some piscivory has also been observed. Unless controlled by predation, yellow perch populations can dominate small lakes and exclude other fishes through competition for food. Salmonids fare especially poorly in these circumstances.

RESUMÉ

Brown, T.G., Runciman, B., Bradford, M.J., and Pollard, S. 2009. A biological synopsis of yellow perch (*Perca flavescens*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2883: v + 28 p.

Le présent synopsis examine les données biologiques sur la perchaude pour appuyer une évaluation des risques portant sur les effets de l’expansion de son aire de répartition vers des régions non indigènes au Canada. La perchaude est un poisson de petite taille de la famille des perches et indigène de l’Amérique du Nord septentrionale, à l’est de la ligne continentale de partage des eaux. Son aire de répartition s’est étendue à la suite d’introductions réalisées aux profits de la pêche sportive ou de son utilisation comme espèce fourrage pour d’autres espèces. La perchaude montre des préférences très variées en matière d'habitat et elle est particulièrement prolifique dans les petits lacs. Elle est généralement présente dans la zone littorale, où elle se nourrit d’invertébrés benthiques, même si, dans certains cas, elle peut également se nourrir de zooplancton dans les grands lacs. On a également relevé des spécimens piscivores. À moins d’être contrôlées par la prédation, les populations de perchaudes peuvent être dominantes dans les petits lacs et exclure les autres poissons par la compétition pour la nourriture. Les salmonidés montrent des résultats médiocres dans de telles circonstances.

1.0 INTRODUCTION

The yellow perch *Perca flavescens* is a small to moderate-sized member of the family Percidae, often distinguished by its yellow or brassy colour and the dark vertical stripes on its body. It is typical of bony fish and is often used to demonstrate common fish anatomy and physiology (Scott and Crossman 1973). The flesh is considered tasty, and the species is an important part of recreational and commercial fisheries, especially in the eastern U.S. and Canada. Adults range from 10-15 cm in stunted populations up to 25-30 cm in others (Scott and Crossman 1973). Although a large yellow perch can be well over 30 cm and 1 kg (Wydoski and Whitney 2003), it is typically caught at smaller sizes.

Yellow perch inhabit small and large lakes, slow moving rivers, and brackish waters. The expansion of their range in North America is largely through introductions by resource agencies or by illegal introductions.

While native to much of Canada, yellow perch may present risks to native biota and aquatic ecosystems if introduced outside its natural range. Largely because of the unauthorized introduction of yellow perch to British Columbia lakes, Fisheries and Oceans Canada (DFO), through the Centre of Expertise for Aquatic Risk Assessment (CEARA) has conducted an assessment of the risks associated with its spread. The present biological synopsis provides the background to that risk assessment, and includes yellow perch biology and natural history, current distribution, use by humans and known impacts.

1.1 NAME, CLASSIFICATION AND IDENTIFIERS

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Superclass: Osteichthyes
Class: Actinopterygii
Order: Perciformes
Family: Percidae
Genus: *Perca*
Species: *flavescens*

Scientific Name: *Perca flavescens* Mitchill, 1814

Common names (English): yellow perch, American perch, lake perch
Common Names (French): perchaude
Integrated Taxonomic Information System Serial Number: 168469
Sources: Adapted from Nelson and Paetz (1992); Zip Code Zoo (2008)

1.2 DESCRIPTION

Yellow perch is oval shaped with a deep, laterally compressed, oblong body (Figure 1). The distinct golden or brassy colour varies with size and habitat. The dorsal and caudal fins are usually olive coloured, while the pelvic and anal fins are typically greenish or yellow-orange. The belly is usually a pale cream. The vertical bands that run from the dorsal area fade gradually near the belly. They may be faint in young perch, while the colours of spawning males are more intense.

Figure 1. Yellow Perch *Perca flavescens.* Image courtesy of the New York State Department of Environmental Conservation, Albany NY.

The Percidae can be distinguished from other closely related families by the separation of the dorsal fins. The soft rear fin has 12 to 15 rays plus 1 or 2 spines, while the spiny anterior fin has 13-15 spines (Scott and Crossman 1973). The anal fin has two spines; spines are present on the opercula tip, and the caudal fin is forked. The pelvic fins are close together (Eddy 1957). There are 7-8 branchiostegal rays, The mouth contains many fine teeth. The lateral line is slightly arched and has 51-61 scales over its length (Scott and Crossman 1973). Ctenoid scales give the yellow perch a rough feel.

1.2.1 Taxonomy and genetics

The family Percidae are characterized by a separated dorsal fin completely divided into a spiny and a soft-rayed portion, and by an anal fin that bears one or two spines (Eddy 1957). The Percidae family contains about 200 species (mostly darters) in ten genera divided into 3 subfamilies, one of which is the Percinae or perches. The suborder Percoidei includes perches, darters, bass and sunfish.

The name *Perca* is derived from the early Greek for "perch;" *flavescens* means "becoming gold" or "yellow coloured" in Latin. The genus *Perca* contains three species. Yellow perch has sometimes been classified as a “subspecies” of the European perch (*Perca fluviatilis* Linneaeus, 1758), because of their similar morphology and ability to cross-breed. The European perch from Eurasia and the yellow perch from North America are recognized as sister species but have been considered conspecific (Carney and Dick 1999). The Balkhash perch (*Perca schrenkii* Kessler, 1874), found in Kazakhstan is the third member of the *Perca* genus and is very similar to the European perch (Mamilov 2000).

2.0 DISTRIBUTION

Roberge et al. (2001) characterized yellow perch as a highly adaptable species that can utilize a wide range of different habitats to extend its range. This view is supported by studies of other members of the Family Percidae. Percids are generally hardy species with broad environmental tolerances (Craig 1987). However, their distribution may be limited by biotic and abiotic factors including temperature, salinity, intra- and/or interspecific interactions, disease and the availability of food and spawning resources. For example, while the southern limit for percid survival is approximated by the 31^{O}C summer air isotherm, northern distribution may be limited by indirect effects of temperature on growth, maturation and food production (Craig 1987).

2.1 GLOBAL NATIVE DISTRIBUTION

Yellow perch is a North American species whose native distribution was the result of post-glacial dispersal from the Mississippi River (McPhail and Lindsay 1970; Scott and Crossman 1973). This distribution extended over much of northern North America east of the Rocky Mountains (Figure 2), including tributaries to the Arctic and Atlantic Oceans and the Mississippi River.

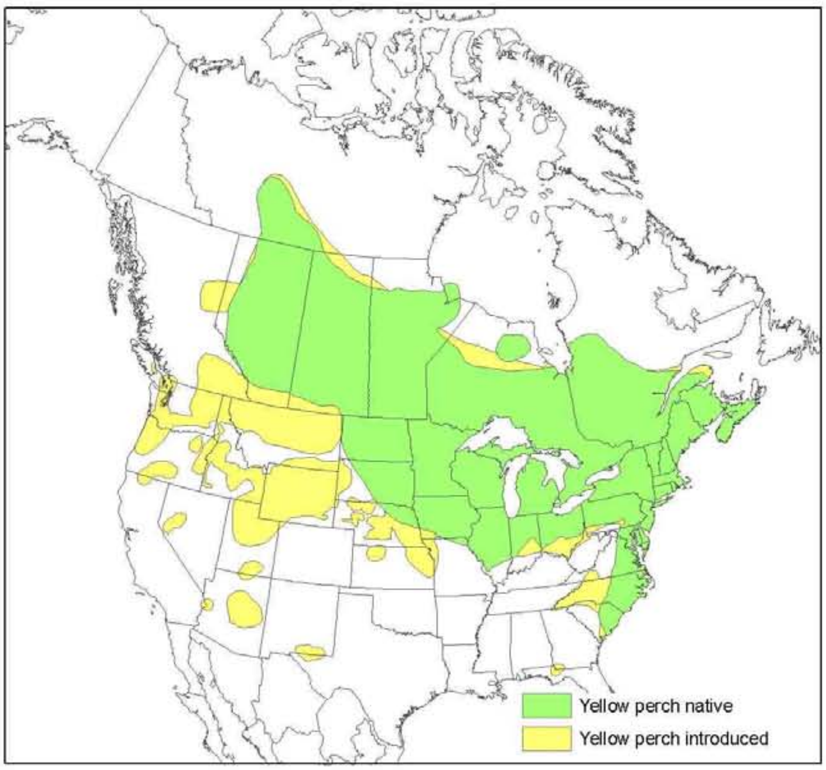

Figure 2. Native and introduced range of yellow perch in North America from Bradford et al. (2008).

In the United States, native yellow perch occur from Montana and eastern Kansas in the west, through northern Missouri to western Pennsylvania in the south and from Maine to South Carolina in the east (Scott and Crossman 1973).

2.2 NATIVE DISTRIBUTION IN CANADA

In Canada, native distribution of yellow perch includes all major drainages from Nova Scotia and Quebec north to James Bay, northwest to Great Slave Lake and west into Alberta. Yellow perch are not native to the Yukon Territory, British Columbia, Prince Edward Island, Newfoundland or Labrador (Scott and Crossman 1973). There is one possible exception: Swan Lake, in the Peace River drainage of northern B.C., is occasionally cited as within its native range (McPhail and Carveth 1994). Local accounts indicate this population may have originated from fish stocked in Sturgeon Lake or Winagami Lake in Alberta between 1969 and 1980, although McPhail (2007) notes that yellow perch were present in Swan Lake before this period and may indeed be native.

2.3 NON-NATIVE DISTRIBUTION

While still limited to North America (Craig 1987), the distribution of yellow perch has been greatly expanded by human introductions and dispersal (Figure 2). The species has been introduced into many regions in North America from which they were historically absent, including most of the western United States (Moyle 2002). Many non-native fish introductions in this area date from the late 19th and early 20th centuries and were conducted by the U.S. Fish Commission. Such stocking was less prevalent in Canada.

In Canada, the largest increase in non-native distribution has been in British Columbia, where yellow perch have been introduced to a number of lakes in the Peace River drainage. The species is now also found in a number of areas in southern B.C. including waterbodies in the Columbia, Kootenay, Thompson, lower Fraser and Vancouver Island drainages (Runciman and Leaf 2009).

2.4 MODES OF INVASION AND RATE OF SPREAD

Once established, populations of non-native fish can disperse through connected waters into adjacent habitats. Thirteen of 50 yellow perch occurrences in British Columbia are contiguous with yellow perch-bearing trans-boundary waters. Yellow perch were introduced into eastern Washington State in the late 1800s, and most of the B.C. populations (in the Kettle, Kootenay, Pend d’Oreille, and Okanagan river systems) arrived from downstream sources (McPhail 2007). Moyle (2002) indicated that yellow perch in the Klamath River system populated suitable habitat downstream of the reservoirs they were originally planted in.

Aquatic invasive species may be introduced outside their native range through government-authorized stocking programs. CCFAM (2007) has also identified seven key non-authorized pathways for their introduction. These are:

shipping,
recreational and commercial boating,
construction of new canals and water diversions,
releases from live food fish markets,
releases from the aquarium and water garden trade,
use of live bait,
illegal introductions to create new fisheries.

In addition to authorized introductions, the most likely of these unofficial pathways are illegal introductions, dispersal through connected waterways and live bait.

2.4.1 Authorized introductions

Invasive fish species have commonly been introduced into new North American water-bodies legally. These introductions are often by governmental agencies or sports groups in partnership with them. The usual goal is creation of recreational fishing opportunities or to improve the forage base for existing fisheries. For yellow perch, many of these introductions have been successful (Figure 2). In Canada, introductions are currently regulated by the National Code on Introductions and Transfers of Aquatic Organisms (CCFAM 2003). The introduction of yellow perch by Provincial fisheries staff into Stony, Kelly, Bearhole and Charlie Lakes in the Peace River watershed are examples of this type of introduction.

2.4.2 Illegal introductions

This type of introduction has been termed the “bucket brigade.” Most of the introductions in British Columbia appear to be of this type (Runciman and Leaf 2009); it is unknown whether individuals or groups are responsible. Hatfield and Pollard (2006) note that illegal stocking of yellow perch in small lakes may be a prelude to future bass or walleye introductions. Thirty-one lakes and streams in southern British Columbia with established yellow perch populations also support introduced smallmouth bass, largemouth bass or walleye. It is possible that the people responsible for illegal yellow perch introductions hope they will become an established forage fish for bass or walleye.

2.4.3 Live bait

A common avenue of introductions of yellow perch in eastern Canada and the U.S. has been through their use as bait for larger sport fish such as walleye, pike, and bass (Scott and Crossman 1973; Litvak and Mandrak 1993). Yellow perch can escape despite prohibitions on their deliberate release. The use of live fish as bait and the transport of live fish are prohibited in British Columbia. However, these activities continue to be reported by Conservation Officers.

3.0 BIOLOGY AND NATURAL HISTORY

3.1 AGE AND GROWTH

Newly-hatched perch are 5 mm long and move immediately into near-shore pelagic schools. There is no parental care. Fins develop fully during the first summer (Craig 1987). The pelagic phase usually lasts 30-40 days (Shroyer and McComish 2000; Fulford et al. 2006b). Larvae (<9.5 mm) are unable to maintain position at water velocities above 2.5 cm/s (Houde 1969). Survival of larval yellow perch has been linked to predation (Shroyer and McComish 2000) and to prey community structure (Siefert 1972; Bonar et al. 2005; Fulford et al. 2006b).

Yellow perch exhibit size-related sexual dimorphism. In the north, males reach sexual maturity in 2-3 years; females tend to be larger and are sexually mature in 3-4 years (Scott and Crossman 1973; Becker 1983; Moyle 2002). Females live longer than males (Scott and Crossman 1973). Purchase et al. (2005) examined yellow perch from 72 Ontario lakes and concluded that females grew faster, reached larger maximum sizes, matured later (and at a greater size), and lived longer than did males.

Yellow perch do not grow as large in northern waters, but may live longer. In Alberta lakes yellow perch of 15 years in age have been recorded (M.J. Sullivan, Alberta Fish and Wildlife Division, pers. comm., 2007.) Estimates of maximum age vary widely however. Roberge et al. (2001) stated that the maximum age averages from 9-10 years, with a few living more than 11 years. In Washington State, two populations of yellow perch lived through 9 growing seasons in Lake Roosevelt and 10 growing seasons in Lake Stevens (Wydoski and Whitney 2003). Krieger et al. (1983) indicated that the maximum age of yellow perch was usually 9-10 years.

The morphology of a lake appears to be a major factor in yellow perch growth and its eventual level of dominance. Keast (1985) found perch grew best in Atkins Lake, a small, warm Ontario lake where, in the absence of competitors, they were piscivorous by year one. Yellow perch can be the most abundant piscivore in small lakes, or the only one (ie. cannibalistic). However, growth was also good in Sunfish Lake where they were pure planktivors. Growth was poorest in oligotrophic, cold, deep, lakes (Keast 1985).

Yellow perch grow at different rates in different lakes, and 20% of this variability was explained by differences in lake surface area (Purchase et al. 2005). After examining the relationship between littoral area and growth, this study concluded that yellow perch growth did not appear to be related to the amount of littoral habitat available, but was likely related to species diversity (larger lakes tend to be more diverse). Fish species diversity is correlated negatively with the relative importance of yellow perch in the fish community (Clady 1978). It was suggested that fish community interactions may be a major influence on yellow perch growth (Purchase et al. 2005).

When perch out-breed and out-compete other species, especially in smaller lakes, stunted populations of yellow perch become common (McPhail 2007). They can survive and reproduce in colder trout lakes, reducing growth and survival of trout by competing with them for food (Moyle 2002); the result is high densities of small yellow perch. Opportunistic feeding may account in part for stunting (Ney 1978).

3.2 PHYSIOLOGICAL TOLERANCES

Yellow perch is a shallow-water species and Moyle (2002) states that perch are, “almost always associated with the heavy growth of aquatic plants at depths of 1-10 m”. They have been found deeper than 15 m, but at that depth they are usually associated with the bottom (Ferguson 1958). Excursions to even deeper water may occur (Scott and Crossman 1973).

3.2.1 Temperature

Yellow perch is adaptable to warm or cool habitats, with a preferred summer temperature range of 17.6 to 25^{O}C (Ferguson 1958; Krieger et al. 1983). Optimum temperature ranges from 21 to 24^{O}C, with an upper lethal limit of 26.5^{O}C (Scott and Crossman 1973). Other authorities place the upper limit higher. Black (1953) cites a value of 33^{O}C; Hokanson (1977) indicated that 32^{O}C was lethal for yellow perch and observed stress behaviour at temperatures above 26^{O}C. Ferguson (1958) considered the summer upper lethal temperature to be 32.3^{O}C.

Water temperature is critical to spawning success (Clady 1976). Scott and Crossman (1973) reported that perch spawned in the spring when the water temperature was between 6.7 and 12.8^{O}C. In the northern U.S., larval survival was considered optimum at 16^{O}C and was low below 14^{O}C (Clady 1976). Hatching times were 10-26 days shorter in the warmer surface waters of a turbid lake when compared to those in cooler, deeper waters in the same lake, or in the cooler surface waters of a less turbid lake (Huff et al. 2004). Fry are inactive below 5.3^{O}C, with growth initiated at approximately 6 to 10^{O}C (Hokanson 1977).

3.2.2 Ultraviolet radiation

The level of ultraviolet radiation (UVR) is considered important in hatching success of yellow perch (Williamson et al. 1997). In a Pennsylvania study, incubation success was dependent upon the degree of exposure to UVR at different depths with different dissolved organic carbon (DOC) concentrations (Huff et al. 2004). High levels of UVR in surface waters with low DOC killed 100% of the yellow perch eggs, while UVR had little impact on egg survival in the high DOC lake. Depth of spawning differed, as 92% of the eggs deposited in the low DOC lake were at depths greater than 3m while 76% of the egg masses in the higher DOC lake were spawned at less than 1m. The authors suggest that perch spawn at greater depths to avoid UVR, but deeper spawning may reduce developmental rates because of the lower temperature (Huff et al. 2004).

3.2.3 pH

Yellow perch can survive and grow in infertile Michigan lakes with alkalinities of between 3-10 mg/liter; however, annual survival may be low (Clady 1977). A pH of 7 to 8 is considered desirable for the growth of yellow perch (Wallat et al. 2005), but the species is relatively tolerant of low pH. In Ontario lakes, for example, they are found in waters ranging from approximately pH 3.9 to 9.5 (Rahel and Magnuson 1983; Kelso and Johnson 1991). Perch were sampled from a northern Wisconsin lake with a pH of 4.5 (Nelson et al. 1988). Histopathological effects were noted in yellow perch when two Wisconsin lakes were experimentally acidified to pH 5.1 and 4.7 (Leino and McCormick 1993).

3.2.4 Salinity

Yellow perch have been found in brackish and saline waters (Scott and Crossman 1973). This upper range is much higher than the 12 ppt upper limit used for modeling in the Severn River, Maryland (Victoria et al. 1992) or the 10.3 ppt suggested for Manitoba lakes (Driver and Garside 1966; Scott and Crossman 1973).

3.2.5 Oxygen

Yellow perch are relatively tolerant of low dissolved oxygen (DO) (Scott and Crossman 1973). Winter dissolved oxygen levels of 0.2-1.5 mg/l are considered lethal (Moore 1942; Magnuson and Karlen 1970), and 5 mg/l is considered the lower optimum limit (Krieger et al. 1983). Moore (1942) reported that a summer DO concentration of 3.1 mg/l was lethal at 26^{O}C. In aquaculture ponds, levels of oxygen are maintained at 5.0 mg/l to 7.0 mg/l (Wallat et al. 2005).

3.3 REPRODUCTION

3.3.1 Maturation

Generally, all males are sexually mature at 3 years; most females age 4 and older, or longer than 160 mm, were mature (Schneider 1984). Adult perch must be exposed to an extended period of cool water temperatures to ensure egg maturation (Krieger et al 1983); this minimum temperature was estimated to be 10^{O}C (Hokanson 1977). Spawning takes place when water temperatures reach 6-7^{O}C, although spawning may in fact be more dependent upon photoperiod (Scott and Crossman 1973).

3.3.2 Spawning location, timing and behaviour

Yellow perch spawn once a year in large schools, using shallow areas of a lake or tributary streams with little current (Krieger et al. 1983). Yellow perch spawn in spring

(April-May) in British Columbia, but may spawn earlier in southern areas (McPhail 2007). Scott and Crossman (1973) specify spawning at night or early morning, although other authors have indicated that spawning takes place during both night and day (Herman et al. 1959; Craig 1987). Females may spawn up to eight times in their lifetime (Bart and Page 1992).

Spawning depth ranges from 0.5-13 m, but tends to be shallow. Krieger et al. (1983) reported that yellow perch spawn at depths of 1 to 3.7 m, while depths ranging from 0.5 to 8 m have been indicated by Craig (1987). No redd or nest is constructed. Males arrive on the spawning grounds first (Scott and Crossman 1973). Two to five males usually accompany each female as she deposits her egg mass (Mangan 2004); at least two males release milt over the eggs (Herman et al. 1959). Egg and sperm release takes about five seconds. Females leave immediately after egg release, while males remain for a short time. The males do not appear to guard the eggs or fry (Scott and Crossman 1973; Craig 1987).

The average egg mass of 23,000 eggs (range 2,000 to 90,000) is a semi-buoyant, jelly-like spiral up to 2 m long and weighing 0.9 kg (Scott and Crossman 1973). A portion of the egg strand usually adheres to vegetation or substrate while the remainder moves with the water. Yellow perch eggs are seldom eaten by other fishes and it has been suggested that the jelly-like sheath that protects the eggs may contain a chemical which makes them unpalatable (Newsome and Tompkins 1985). Eggs usually hatch in 8 to 10 days (Roberge et al. 2001), and the yolk is absorbed within the next 5 days (Trautman 1957 cited by Roberge et al 2001). Hatching may take up to 21 days depending upon temperature. The availability of suitable spawning habitat is critical in determining hatching success (Mangan 2004).

Schneider (1984) reported that fecundity was more strongly related to parental length and weight than to age. Scott and Crossman (1973) indicated a perch 131 mm in length might contain 36,600 eggs, while a fish 254 mm could contain 109,000 eggs.

A fast-growing perch has a higher probability of being mature, and producing more eggs, than a slow-growing one. The strength of a given year-class appears to be positively correlated with the rate of spring warming during incubation and hatching (Hartman 1972). Schneider (1984) concluded that growth, maturity, and fecundity were density sensitive and compensatory, and that mortality of juveniles and adult yellow perch was either density independent or depensatory. Thus, total egg production could be higher for large, slow-growing year classes than for small, fast-growing ones (Schneider 1984).

3.4 FEEDING AND DIET

The diet of yellow perch changes with age and body size. Larval and young perch tend to consume zooplankton. Age one yellow perch may shift to midges and dipterans (Shrader 2000). Larger perch may be predominantly piscivorous as well as cannibalistic (Scott and Crossman 1973).

3.4.1 Larval diet

A variety of factors including wind speed (Whiteside et al.1985), turbidity, and food availability (Noble 1975) appear to influence the survival of larval yellow perch. In a large lake (Lake Erie) food composition differed for populations caught in different areas (MacDougall et al. 2001).

The survival of yellow perch larvae depends on a plentiful supply of zooplankton early in the year (Kelso and Ward 1977). The diet of 6 mm yellow perch larvae consisted primarily of zooplankton such as copepod nauplii, cyclopoid copepods, and cladocerans (Siefert 1972; Kelso and Ward 1977). *Diaptomus* sp. and *Diaphanosoma* sp. were common in eastern US reservoirs (Krieger et al. 1983). In Lake Roosevelt, Washington, the most abundant food items in larval yellow perch stomachs were calanoid and cyclopoid copepods, while cladocerans were not important (Faurot and White 1994). However, young yellow perch in Oregon reservoirs were found to consume considerable amounts of larger zooplankton (Shrader 2000); the majority were larger calanoid copepods and Daphnia, while cyclopoids (smaller zooplankton) were almost non-existent in the diet. On average, yellow perch selected for larger sized zooplankton and avoided smaller sized taxa (MacDougall et al. 2001). In northern Michigan's Kettle Lake, young yellow perch consumed the most abundant (*Bosmina longirostris*) and largest (*Diaphanosoma brachyurum*) species of cladocerans (Baltzer and Swinehart 2005).

Lake morphology can influence development of larval feeding patterns (Bonar et al. 2005). Siefert (1972) compared yellow perch diet in a small, shallow (3.1m), eutrophic lake with a deeper (34m), oligotrophic lake. Yellow perch larvae in the shallow lake fed first on copepod nauplii, then on copepodites, and finally switched to larger copepods and cladocerans. In the deeper lake, the yellow perch larvae first selected rotifers and never showed a preference for cladocerans. Fulford et al. (2006b) noted that yellow perch larvae made three distinct transitions in prey selection: from rotifers to small copepods to large copepods to cladocerans. They felt the first and third transitions were dependent on the composition of the prey community. Bonar et al. (2005) suggested that the ability to switch diet pathways illustrated plasticity in feeding behaviour and that yellow perch can thrive in a wide range of lake communities. Fulford et al. (2006b) hypothesized that perch life history was optimized for smaller, more productive systems, where larval survival was more consistent between years.

3.4.2 Juvenile and adult diets

The amount of zooplankton in the diet of yellow perch tends to decline with age and growth. Diet shifts toward larger prey items such as ostracods, amphipods, and chironomid larvae (Krieger et al. 1983). Juvenile yellow perch are primarily littoral bottom dwellers and they feed on cladocerans, ostracods, and chironomid larvae on the bottom and throughout the water column (Scott and Crossman 1973). Yellow perch stomach analyses from New Brunswick lakes indicated juvenile yellow perch ate primarily dipteran larvae and larger aquatic invertebrates (Peterson and Martin-Robichaud 1982).

In smaller wetlands, yellow perch less than a year old fed selectively on larger *Daphnia sp.* over two years of study (Mangan 2004). Bosmina, Odonata and Amphipoda were also major prey items, with some chironomids and copepods. Trichoptera and Ephemeroptera were found infrequently. Chironomidae, Tricoptera, and Amphipoda had the highest benthic invertebrate densities while Ephemeroptera had the lowest.

Larger adult perch continue to consume insects and invertebrates as well as fish eggs, juvenile fish and crayfish. In New Brunswick lakes, adult yellow perch consumed larger aquatic insects, invertebrates, and fish (Peterson and Martin-Robichaud 1982). Costa (1979) described their diet items as cottids, mysid shrimps, and chironomid pupae and larvae. Eggers et al. (1978) indicated that the older age-classes of yellow perch, while still feeding on the bottom, tended to feed more in the water column. Costa (1979) observed maximum feeding just before dark, with no difference between food items taken by different adult size groups; he estimated a daily ration of 1.4% of wet body weight.

In St. Clair Lake, Michigan, 589 yellow perch stomachs were examined (Thomas and Hass 1998). Chironomid larva (84%) occurred in twice as many stomachs in June than chironomid pupae (38%). In September, chironomid larvae (34%) were present in 10 times more stomachs than chironomid pupae (3%). Tricoptera were found in 14% of the stomachs in June and 23% in September. Ephemeroptera nymphs occurred with high frequency in both June (80%) and September (49%), isopods were common in June (20%), and fish were present in 20% of yellow perch examined in September.

3.5 HABITAT REQUIREMENTS

3.5.1 Natural and man-made habitat

Yellow perch typically inhabits warm and cool lakes and ponds; it will also reside in low velocity rivers and has been found in brackish and saline waters (McKenzie 1959, Scott and Crossman 1973). Yellow perch are more abundant in lakes and the backwaters of large rivers than they are in faster-flowing river sections and smaller streams. They are also found in a number of man-made lakes, reservoirs, and river impoundments.

Yellow perch are widely distributed and can be found in aquatic systems ranging in size from 0.1 to 52,000 km^2 (Fulford et al. 2006a). Within these bodies, perch are usually found along the shore among reeds and aquatic weeds, floating docks, and other structures. Yellow perch school naturally and occur in high densities within aquatic vegetation. They are associated with the shallow waters of lakes and large ponds (1-10 m in depth), especially small weedy waterbodies with muck, sand, or gravel bottoms. Yellow perch are less abundant in clear, deep unproductive lakes or in the limnetic zone (Kitchell et al. 1977).

Suitable river habitat resembles lacustrine habitat with pools, slack water, and moderate (> 20% of area) vegetation (Kitchell et al. 1977). Although they are not very common in these areas, Moyle (2002) reports that yellow perch have spread downstream from reservoirs into suitable ponds and backwaters along the Klamath River in northern California.

3.5.2 Spawning habitat

Spawning substrate can include sand, gravel, rubble and vegetation (Craig 1987). In small wetlands in South Dakota, a preferred spawning medium is submerged conifers in shallow water (Mangan 2004). In Lake Michigan, in the absence of aquatic macrophytes and woody material, yellow perch spawned in cobble and mixed cobble and sand, but avoided fine substrates (Robillard and Marsden 2001). Roberge et al. (2001) described spawning habitat as areas with rooted vegetation, submerged brush, and sunken logs over sand and gravel substrates. Krieger et al. (1983) assumed that sites with at least 25% vegetative cover would be optimal spawning habitat. Mangan (2004) felt that lakes in South Dakota were limited in natural spawning substrate, and that introduced conifers (especially short-needle spruce) increased both spawning habitat and hatching success.

3.6 INTERSPECIFIC INTERACTIONS

Yellow perch is preyed on by almost all other warm to cool water predatory fishes such as bass, sunfish, crappie, walleye, northern pike, muskellunge, other yellow perch and lake trout (Scott and Crossman 1973). The importance of native yellow perch to the productivity of these top predatory fish has been examined in several studies. Van De Valk et al. (1999) found that yellow perch are the main prey for walleye and also that perch and walleye populations are tightly coupled. Walleye consumed 58% of the age-0 yellow perch and 47% of the age-1 yellow perch in this study.

Although older, larger, piscivorous salmon from the Great Lakes will consume yellow perch, after some experience with yellow perch they were reluctant to attack them and would break off attacks in favour of other prey (Savitz and Bardygula-Nonn 1997). Lake trout in eastern North America also had a preference for more pelagic and easily assimilated species (alewives) (Savitz et al. 1991).

3.6 BEHAVIOUR AND MOVEMENTS

3.6.1 Seasonal and diurnal movements

Perch exhibit strong diel behaviour (Scott and Crossman 1973), and light levels appear to be a critical determinant of activity. They are active during the day and inactive at night (Helfman 1979; Craig 1987). Perch are not generally caught at night. Vision is considered necessary for schooling; perch schools tend to break up at dusk and reform in the morning (Hergenrader and Hasler 1968; Helfman 1979). Normal diel behaviour is lost during spawning, as the perch become active both day and night (Craig 1987).

Larval yellow perch utilize nearshore and offshore habitats between hatching and transition to a demersal habitat. Although larval perch were more abundant at the nearshore surface at night than during the day, larval perch > 15 mm in Lake Michigan were captured in the epilimnion, more than 5 km from shore. This suggests that older larvae can travel considerable distances in large open systems.

Yellow perch do not travel far throughout the year but will move into deeper water to overwinter and returned to shallow water in spring to spawn (Herman et al. 1959). The seasonal movements of yellow perch tend to follow the 20^{O}C isotherm (Scott and Crossman 1973). Dahlberg (1981) used gill nets to sample the fish community of Cayuga Lake, N.Y., and concluded that water temperature was the most important factor in fish distribution. He noted that yellow perch were concentrated in inshore surface waters during the summer.

3.6.2 Migration

Some yellow perch appear to be migratory (Newbrey et al. 2001), but migrations tend to be short and local. Yellow perch in Lake Winnebago migrated 40 km upstream to spawn (Weber 1975 cited in Newbrey et al. 2001). Similar spawning runs have been noted in the Wolf River (Weber and Les 1982). Yellow perch have been observed entering a tributary stream of Lake Superior during flood stage, while spawned adults and progeny moved downstream in the fall (Manion 1977). Yellow perch may move upstream into fresh water from brackish water (Scott and Crossman 1973). In the Chesapeake Bay, yellow perch have developed a semi-anadromous lifestyle (Scott and Crossman 1973). The adults migrate into tidal and non-tidal freshwater to spawn, then move downstream into brackish waters for all other phases of their life cycle.

3.6.3 Swimming behaviour

Yellow perch are relatively poor swimmers; they do not accelerate quickly, and have trouble ascending barriers. In a bibliography on the effects of stream barriers on fish movement, Newbrey et al. (2001) reported that no information was found on the leaping ability of yellow perch.

A speed of 54 cm/s was the highest speed recorded for a school of perch (Hergenrader and Hasler 1968); individual fish outside the school commonly swam at less than half the school's speed. The median critical swimming speed of yellow perch acclimated at 10 and 20^{O}C was 21.0 cm/s and 33.0 cm/s respectively (Otto and Rice 1974). Swimming speed peaked at water temperatures of $20\text{-}25^{O}$C (Hergenrader and Hasler 1968).

Yellow perch are a schooling fish, and this behaviour may provide protection for younger fish and better feeding for older ones (Craig 1987). The schools have been described as spindle shaped, containing 50 to 200 fish arranged by size and age (Herman et al. 1959). Schooling could in part make up for poor swimming ability. Young perch have a greater schooling tendency than older, larger fish, which occasionally travel alone (Helfman 1979). Schools of young perch are often observed near shore, while schools of adults are generally found farther out. Females and males often form separate schools (Craig 1987) and juvenile perch may occasionally form schools with other minnow species in shallow near-shore habitats (Scott and Crossman 1973).

3.7 DISEASES AND PARASITES

3.7.1 Populations in eastern North America

In eastern North American lakes, yellow perch and salmonids share parasites and diseases. Parasitic copepods *Ergasilus* sp. common to chinook, coho, and yellow perch have been noted in Lake Michigan (Buttner and Hamilton 1976). Eastern yellow perch are also commonly infected with the brain parasite *Flexibactor collumaris* (Rommel 2001), and red worm *Eustrongylides tubifex* is common in eastern lakes. In the St. Lawrence River, the abundance of the eyefluke *Diplostomum sp*. was higher in perch communities close to colonies of ring-billed gull, an important host. Yellow perch can be infected with broad tapeworm *Diphyllobothrium latum* (Hoffman 1967).

Considerable concern has arisen in Ontario following the recent discovery of the parasite *Heterosporis sp*. (Great Lakes Fishery Commission 2007). Prior to 2000, *Heterosporis* was known only to tank-reared aquarium species. In 2000, it was identified in Wisconsin yellow perch and has since been found in Minnesota, Michigan, and Ontario (Great Lakes Fishery Commission 2007). While there is no evidence that *Heterosporis* can infect people, fish including rainbow trout, coho salmon, brook trout, brown trout, lake trout, white sucker, channel catfish, fathead minnow and largemouth bass could be infected in laboratory conditions (Sutherland 2004; Great Lakes Fishery Commission 2007). In Wisconsin Lakes, trout-perch, burbot, pumpkinseed, sculpin, rockbass, walleye, and northern pike have been found with infections of *Heterosporis* (Great Lakes Fishery Commission 2007).

Heterosporis doesn’t necessarily kill an infected fish, but when an infected fish dies, other fish may become infected through its consumption or contact with spores released into the water (Great Lakes Fishery Commission 2007). It is also possible that spores may survive and pass through the digestive tract of herons, cormorants and loons. The flesh of severely infected fish becomes inedible (Sutherland 2004). Yellow perch commercial fishers in Lake Ontario are very concerned about Heterosporis since infected perch are not marketable, and current infection rates are 5% of harvest (Sutherland 2004).

Viral hemorrhagic septicemia (VHS) is considered a serious systemic disease of fish and is an emerging disease in the Great Lakes (Fisheries and Oceans Canada 2008). Fisheries and Oceans Canada (DFO) determined that the VHS virus detected in the Great Lakes is a North American strain, and most closely related to the strain found on the east coast. In May 2006, thousands of dead drum appeared on northern beaches of Lake Ontario. VHS disease has since been found in 12 species of Great Lakes fish including yellow perch. An extensive 2006 die-off of yellow perch in Lake Erie was attributed to VHS. Ontario has taken action to prevent the transfer of VHS by restricting commercial bait licenses (Ontario Ministry of Natural Resources 2007).

<u>3.7.2 Introduced populations</u>

In Lake Oroville CA, yellow perch is an introduced fish on which few diseases or parasites have been noted. There is little information on warm water diseases present and their impacts on the fishery (Keefe 2003). It was speculated that potentially significant warm water diseases might include columnaris and epistylis (red sore disease). However, epistylis was observed in bass, not in yellow perch. Bangham and Adams (1954) noted that no parasites were found on 18 yellow perch examined in a California survey.

Bangham and Adams (1954) examined 16 yellow perch taken near Osoyoos, British Columbia. Only three had any parasites and only two species of parasites were found (*Ligula intestinalis* and *Neascus sp*). This compares to yellow perch found carrying 29 different species of parasites in Manitoulin, and the 27 noted on yellow perch in Wisconsin (Bangham and Adams 1954).

4.0 USE BY HUMANS

4.1 COMMERCIAL HARVEST

Yellow perch have been commercially fished in central Canada and the United States for over 100 years (Scott and Crossman 1973). Commercial fishers catch large numbers of perch with gillnets, poundnets and trapnets, especially in the Great Lakes (State of Canada's Fishery 2002). In 2002, perch landings in Canada were estimated to be 3,622 tonnes valued at $16.7 million (State of Canada's Fishery 2002). Yellow perch was second in landed value to pickerel ($28.2 million); whitefish was third at $15.2 million.

Yellow perch is the most valuable commercial catch in Ontario (Great Lakes Fishery Commission 2007). Yellow perch support commercial fisheries in Lake Michigan, Lake Erie, and Lake Huron, but do not appear to be as important in Lake Superior or Lake Ontario (Great Lakes Fishery Commission 2007). The species represented 55% of the landed value of all fish taken in Lake Erie by Canada from 1980 to 1984 (Craig 1987). The largest total estimated landing was17 million kg in 1969, worth $3.2 million (Scott and Crossman 1973). The yellow perch is also an important commercial species on the U.S. side as well.

Yellow perch are sold both frozen and fresh (Scott and Crossman 1973). In Canada, yellow perch is sold as fillets and whole fish, although the majority of the Canadian catch is filleted for sale in the United States. The greatest demand is found in the north central United States, with Wisconsin consuming approximately 75% (7-9 million kg) of the Great Lakes catch (Craig 1987). Almost 70% of the yellow perch sales in the U.S. occur within 80 km of the Great Lakes (Malison 2003).

A small commercial fishery has existed in Alberta but it is of limited value (Nelson and Paetz 1992).

4.2 RECREATIONAL HARVEST

Yellow perch is one of the easiest fish to catch, and can be taken in all seasons, including under ice. It responds to natural bait and artificial lures. Its flesh is white, flaky and is excellent eating (Scott and Crossman 1973). In Canada and the United States, yellow perch is valued as a sport fish. Francis et al. (1996) indicated that about 85% of the sport fish caught in Lake Michigan were yellow perch.

A yellow perch recreational fishery requires large fish. Perch have a tendency to overpopulate and become stunted, especially in small lakes where they are the main piscivourous fish. Purchase et al. (2005) felt that Ontario lakes larger than 1,650 ha were capable of producing yellow perch large enough for a fishery. Even in larger lakes where the larger sport fish such as walleye, pike and bass are over-harvested, yellow perch populations can become dominated by fish too small to permit a fishery.

4.3 AQUACULTURE

The aquaculture industry in the U.S. midwest contributes 90,800 kg of yellow perch annually (Malison 2003; Wallat et al. 2005). A number of farms devoted to raising yellow perch have started up in Ohio since 2000, however, yellow perch aquaculture has not expanded rapidly (Wallat et al. 2005). Farm-raised yellow perch are sold to restaurants and retailers as scaled fillets (Malison 2003).

5.0 IMPACTS ASSOCIATED WITH INTRODUCTIONS

5.1 IMPACTS ON FAUNA

<u>5.1.1 Plankton communities</u>

Yellow perch larvae and juveniles select larger zooplankton (Shrader 2000; MacDougall et al. 2001). In Phillips Reservoir, OR, yellow perch densities increased 245% between 1994 and 1999. The zooplankton community in 1994 consisted of larger calanoid copepods (15%) and Daphnia (39%). In 1999 these numbers were reduced to 2% and 24% respectively, while smaller cyclopoids, previously almost non-existent in gamefish and yellow perch diet, increased from 43% to 71% of the zooplankton by number. Shrader (2000) concluded that, as yellow perch became abundant in the reservoir, they caused a shift in zooplankton community structure and size distribution, and that selection of larger zooplankton by yellow perch had driven the zooplankton community towards smaller species.

It is questionable whether a littoral fish can influence plankton communities in a deeper, larger lake. In Lake Washington, WA, the total limnetic fish population was estimated to consume only 1.7% of annual zooplankton production (Eggers et al. 1978). Years after introduction, the yellow perch population represented only 1.4% of the total fish community biomass. Yellow perch over 32 g consumed approximately 20% of their prey volume in small fish.

5.1.2 Benthic macroinvertebrates

Chironomids are an especially important as native fish prey because they are abundant in most lakes, larger than many of the other prey items, and highly available due to their life history patterns. In Lake Washington, chironomids consumed by all littoral fishes constituted half of the benthic biomass (Thut 1969). Yellow perch may consume large numbers of benthic chironomid larvae, and in Lake Washington they shifted from pelagic zooplanktivory to benthic piscivory with age (McIntyre et al. 2006).

5.1.3 Wildlife

In Eastern North America, yellow perch are an important food for birds. Stomach contents in double-crested cormorants *Phalacrocorax auritus* sampled in Lake Ontario suggest the birds were targeting yellow perch (Schneider and Adams 1999). Johnson et al. (2002) and Van De Valk et al. (2002) determined that yellow perch was the major prey of cormorants. Other birds that eat yellow perch include herring gull, heron, eagle, hawk, kingfisher, merganser, loon, white pelican, and diving duck.

In Gardom Lake, a small system of the Okanagan drainage in southern BC, local naturalists claim that the lake's faunal community has changed since the introduction of yellow perch in the 1990's. Fewer bird species and amphibians are observed (B. Jantz, B.C. Ministry of Environment, pers. comm., undated).

5.1.4 Fish

Interspecific competition was defined by Larkin (1956) as "the demand of more than one organism for the same resource of the environment in excess of immediate supply." There could be competition for a specific food item or competition for space. Larkin (1956) felt that mutual predation was a common complication of competitive relationships between freshwater fish species. Where the native fish community is represented by multiple species and the natural environment contains multiple habitat types, it is impossible to predict the outcome of an exotic fish introduction.

Freshwater food chains are short, and communities are characterized more by breadth than by height (Elton 1946). Most fish eat what they have an opportunity to feed on, although some food items might be preferred. Flexibility and adaptability are the rule. Few fish are specialized, and the young of almost all species initially feed on plankton before switching to larger food items as they grow. Even if different fish species eat the same foods, this is not sufficient cause for assuming they are competing. However, a lake has a "carrying capacity," and the production of some species is curtailed by the presence of one or more competitors. Removal of non-sport species of fish from lakes has had spectacular results, and attests to the depressing effect of some fish species on others (Larkin 1956).

An examination of fish diets in Phillips Reservoir, OR indicated that rainbow trout had the most varied diet of the game fish sampled (Shrader 2000). Earlier baseline sampling prior to yellow perch introduction indicated that large Daphnia were important to age 1 hatchery trout. However, following the introduction of yellow perch, trout did not consume Daphnia and their diet did not overlap with that of yellow perch. The most common items in age 1 rainbow trout in summer were diptera, coleoptera, hymenoptera and chironomidae. Thus, rainbow trout were able to switch to alternative prey; Shrader (2000) predicted that trout would be less affected than other warm water game fish in the reservoir.

Experimental outplanting of brook trout, splake, and rainbow trout in a small Ontario lake prior to and after the establishment of introduced yellow perch demonstrated the dramatic impact of yellow perch on trout species (Fraser 1978). Following the establishment of yellow perch, the salmonids drastically changed their food habits, and growth rates were reduced more than 50%. The biomass of trout available after competing with yellow perch was less than the biomass of introduced trout. Fraser (1978) concluded that the salmonids could not compete successfully with yellow perch for the available food supply. Thus, following the establishment of yellow perch in small lakes, even hatchery intervention by out-planting of trout is unlikely to be effective.

In Idaho, yellow perch is the most abundant fish species caught within the Cascade Reservoir, and represents 30-95% of the total recreational catch (Horner and Rieman 1981). In this case, the rainbow trout fishery is supported by releases of catchable trout and coho fingerlings for ice fishing. Shrader (2000) felt that rainbow trout populations will be affected only to the extent that they rely on Daphnia for food.

In the Columbia River system in Washington, yellow perch are abundant but not considered to be a major predator on juvenile salmonids (Zimmerman 1999). Yellow perch have smaller mouths than many piscivores (Keast 1985). They may have their largest effect through limiting recruitment (Tonn et al. 1992), but are less likely to suppress reproduction and recruitment totally.

Bonar et al. (2005) examined predation on coho fry and smolts by other fish in three shallow Pacific Northwest Lakes and found that yellow perch, black crappie, brown bullhead, cutthroat trout, and prickly sculpin did consume some coho. However, the highest percentage of coho salmon (98% of the coho prey) was found in largemouth bass, which represented 51% of the total numeric catch in the three lakes. Most predation occurred in spring when coho smolts were migrating through lakes or when coho fry were moving from creeks into lakes.

In Lake Sammamish, WA, yellow perch had not been considered a major predator on salmonid smolts because of their size in relation to the out-migrating fish. However, following sampling in 2001, 40% of yellow perch contained chinook smolts in spring. Yellow perch may have had the ability to affect chinook migration because of their large population. In May, chinook smolts represented over 50% of yellow perch diet by weight. The mean length of yellow perch consuming chinook was 282mm (Footen 2003).

Where prey sizes vary, smaller yellow perch (43 to >190 mm) consistently captured more small minnows than they did large ones. Thus, where smaller fish (minnows and cottids) are also available, these may be consumed in preference to the larger salmonid juveniles. In Lake Washington, the fish consumed by yellow perch were mainly small, and were usually prickly sculpin (Nelson 1977; Eggers et al. 1978).

6.0 IMPACT SUMMARY

Yellow perch have the ability to affect plankton communities, so their effects on other fish can be indirect as well as direct. Perch grazing can cause zooplankton to become smaller, and potentially less suitable for other species.

Salmonids have generally faired poorly in direct competitive interactions with yellow perch. The impact of yellow perch introductions on salmonids in larger lakes or reservoirs is less clear than it is in small lakes, and may be a related to the presence or absence of predators. Yellow perch population dynamics are affected by the presence of predatory fish such as bass and walleye that will eat spiny-rayed fish. In lakes with these species, perch populations are reduced in number, but the survivors grow quicker, and to larger adult sizes.

In western North America, native predators can also affect introduced yellow perch, although the outcome is difficult to predict. Large Pacific salmon from the Great Lakes selected against juvenile yellow perch, and yellow perch were found in the stomachs of introduced smallmouth bass in Columbia River reservoirs, but were not eaten by native Northern pikeminnow. The high thermal tolerances of yellow perch may allow them to escape predation by lake trout in the summer. Observations like these suggest that native fishes in B.C. may not be effective predators on yellow perch.

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