A Biological Synopsis of Northern Pike (*Esox Lucius*)

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2009

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2885

Fisheries and Oceans Canada Pêches et Océans Canada

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A BIOLOGICAL SYNOPSIS OF NORTHERN PIKE (*Esox lucius*)

by

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Cat. No. Fs 97-4/2885E ISSN 0706-6473

Correct citation for this publication:

Harvey, B. 2009. A biological synopsis of northern pike (*Esox lucius*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2885: v + 31 p.

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ABSTRACT

Harvey, B. 2009. A biological synopsis of northern pike (*Esox lucius*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2885: v + 31 p.

This synopsis reviews biological information on the northern pike in support of a risk assessment evaluating the impacts of its expansion into non-native areas of Canada. The northern pike is a cool-water keystone piscivore whose distribution is circumpolar in North America and Eurasia. In Canada, pike are absent in the Maritimes and most of British Columbia but otherwise widespread. While most populations of northern pike are confined to fresh waters in lakes and rivers, the species can tolerate a wide range of environmental conditions and is relatively easy to introduce outside of its native range. Desirability as a sport fish is the main reason for introduction. Pike usually inhabit shallow weedy areas of lakes and slower moving rivers and are ambush predators. Introduced pike populations can have very significant impacts on native fishes including salmonids through predation.

RESUME

Harvey, B. 2009. A biological synopsis of northern pike (*Esox lucius*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2885: v + 31 p.

Le présent synopsis examine les données biologiques sur le grand brochet 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. Le grand brochet est un poisson piscivore des eaux froides important ayant une distribution circumpolaire en Amérique du Nord et en Eurasie. Malgré qu’il soit absent des Maritimes et de la plus grande partie de la Colombie-Britannique, il est tout de même très répandu au Canada. S’il est vrai que la plupart des populations de grands brochets sont confinées aux eaux douces des lacs et des rivières, l’espèce peut toutefois tolérer un large éventail de conditions environnementales, et il est relativement facile de l’introduire à l’extérieur de son aire de répartition naturelle. L’introduction du grand brochet s’explique par l’intérêt qu’il suscite chez les adeptes de la pêche sportive. Le brochet, qui chasse à l’affût, fréquente généralement les parties herbeuses peu profondes des lacs ainsi que les cours d’eau à courant faible. À cause de la prédation, les populations introduites de brochets peuvent avoir une très grande incidence sur les poissons indigènes, notamment les salmonidés.

1.0 INTRODUCTION

The northern pike is a highly successful and widely distributed predator with an important place in human history. In *The Compleat Angler*, Sir Izaak Walton (1653) devotes more than twenty pages to the species he calls "the tyrant, as the Salmon is king, of the fresh water." While some of Walton's information hasn't stood the test of time and modern biology (we no longer think pike is literally "bred of pickerel weed") there is much in his famous book that is as true today as it was in the seventeenth century. The pike is still "solitary, melancholy and bold;" more to the point for the present review, the species is "brought into some ponds some such Other ways as are past Man's finding out."

It is with this risk in mind – the transport of northern pike to waters outside its native range – that the present synopsis has been written. It provides the biological background that will allow biologists and managers to decide how great that risk is, and what can be done about it. The review draws on existing monographs; the most recent comprehensive synopses are those of Raat (1988) and Craig (1996). There is also a rich primary scientific literature on the species, as well as an annotated bibliography (Crossman and Casselman 1987). While the geographic focus of this synopsis is on northern pike in Canada, the wide global distribution of the species means that relevant information has also been pulled from reports on pike populations in Europe and the United States. The focus in this synopsis is on information that illuminates the species' ability to colonize previously unused habitat, and the impacts often associated with such events.

1.1 NAME, CLASSIFICATION AND IDENTIFIERS

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Superclass: Osteichthyes
Class: Actinopterygii
Order: Esociformes
Family: Esocidae
Genus: *Esox*
Species: *lucius*

Scientific Name: *Esox lucius* Linnaeus, 1758
Common names (English): Northern Pike, Great Northern Pike, Jack, Jackfish, Pickerel, Pike, Great Northern Pickerel, American Pike, Common Pike, Great Lakes Pike
Common Names (French): Brochet, Grand Brochet, Bec de Canard

Integrated Taxonomic Information System Serial Number: 162139
Sources: FishBase; Zip Code Zoo; Animal Diversity Web (all 2007).

1.2 DESCRIPTION

The pikes are an ancient Holarctic family represented by the single genus *Esox*. Like all five species within the genus, northern pike has an elongated body with dorsal and anal fins that are placed well back and allow rapid acceleration (Hubbs and Lagler 2004). The duckbill-shaped head of *Esox lucius* is relatively long (25-30% of an average total length of 46-76 cm) and lacks barbels; the alligator-like jaw is outfitted with an extravagant, recurved dentition described in detail by Scott and Crossman (1973). There are five sensory pores on each side of the lower jaw. The body and most of the head are covered with small cycloid scales. The basic body colour of adult pike is green to brown on the dorsal surface, with lighter flanks bearing whitish spots; the creamy ventral colour extends toward the flanks in fingers that are remnants of the juvenile pattern of vertical bars. The entire body appears to be shot with gold, the effect of thousands of tiny gold spots, one on the edge of each scale. The eyes are yellow and highly mobile (Lefevre 1999). Many of the anatomical features sketched above – the camouflage, the posteriorly-placed fins, the abundant teeth, the large eyes – are the obvious adaptations of a lurking, top predator.

Figure 1. The northern pike *Esox lucius.* Image courtesy of the New York State Department of Environmental Conservation, Albany NY.

Descriptions of larval morphology are contained in the extensive literature on culture of the species (see Section 4.2). The pike larva's most notable anatomical feature is a pair of nasal cement glands that attach newly hatched larvae to the substrate during the yolk absorption stage (Braum et al*.* 1996).

1.2.1 Genetics

The extremely widely distributed *Esox lucius* exhibits genetic differentiation between its many global populations. Analysis of the genetic distance between populations using recently developed genetic markers suggests separate races for northern Europe, southern Europe and North America – a refinement of earlier conclusions based on classic mitochondrial DNA analysis (Maes et al. 2003), and one that will undoubtedly yield more races as more populations are studied. Genetic variation between populations of northern pike is, however, still much lower than the variation found in other fish species, including not only salmonids, but also other species that occupy similar habitats, such as muskellunge (*Esox masquinongy*) and walleye (*Sander vitreum*). Various explanations have been advanced, including demographic factors, genetic drift and genetic bottlenecks during the last glaciation (Senanan and Kapuscinski 2000).

Within populations, accounts of actual genetic variation depend on the tool used to analyze it. Microsatellite DNA analysis, which enables a finer level of discrimination than allozymes and mitochondrial DNA, shows European populations to be more variable than those from North America and Siberia, which are remarkably uniform (Senanan and Kapuscinski 2000; Jacobsen et al. 2005).

2.0 DISTRIBUTION

2.1 GLOBAL NATIVE DISTRIBUTION

The distribution of northern pike is circumpolar in North America and Eurasia, the widest of all species in the genus. It occurs in freshwaters in Canada and the northern United States; Ireland and the United Kingdom; continental Europe south to Italy; around the Dead and Caspian seas; into Siberia and the drainages of Lakes Balkhash and Baikal; and finally east as far as the Chukchi Peninsula (Scott and Crossman 1973; Crossman 1996; Senanan and Kapuscinski 2000). Northern pike are absent from northern Norway and northern Scotland (Lefevre 1999).

The concept of 'native' or 'historic' distribution needs some clarification, because northern pike, as a species of importance for mankind, has probably been intentionally moved to new locations for hundreds of years. The population in Ireland, for example, while often included as part of the native distribution, was deliberately introduced in the sixteenth century; its low genetic variability probably reflects a genetic bottleneck at the time of transfer (Jacobsen et al. 2005). In fact, to apply Taylor's (2004) definition of 'native' as 'exclusive of any human influence' to northern pike would be difficult.

However it is defined, northern pike's broad distribution is testimony to the enormous success of the species, and the ancient pathways taken in its spread over so wide an area have been the focus of several studies. Recent genetic analyses seem to confirm the hypothesis that pike originated in North America and subsequently found their way to Eurasia over the Bering Land Bridge that existed in the Tertiary period (Senanan and Kapuscinski 2000) – a route that is the reverse of the one offered by previous authorities (Hubbs and Lagler 2004). Crossman (1996) summarizes arguments for post-glacial repopulation of Eurasia and North America from two refugia in each region.

2.2 NATIVE DISTRIBUTION IN CANADA

Northern pike are absent in the Maritimes and most of British Columbia but otherwise widespread in Canada: they occur from Labrador throughout Quebec, Ontario, the Prairie Provinces and most of the Yukon and Northwest Territories and the southern portion of Nunavut (Figure 2; Scott and Crossman 1973).

Mandrak and Crossman (1992) indicate the northern pike's extensive distribution throughout Ontario; distribution in Quebec is similarly widespread. The species is common throughout Alberta, and large fish have been taken from Athabaska and other lakes (Paetz and Nelson 1975). It is also ubiquitous in Saskatchewan, where the Canadian record fish was caught (Atton and Merkowsky 1983), and in Manitoba occupies nearly all permanent fresh waters that support fish populations (Stewart and Watkinson 2004).

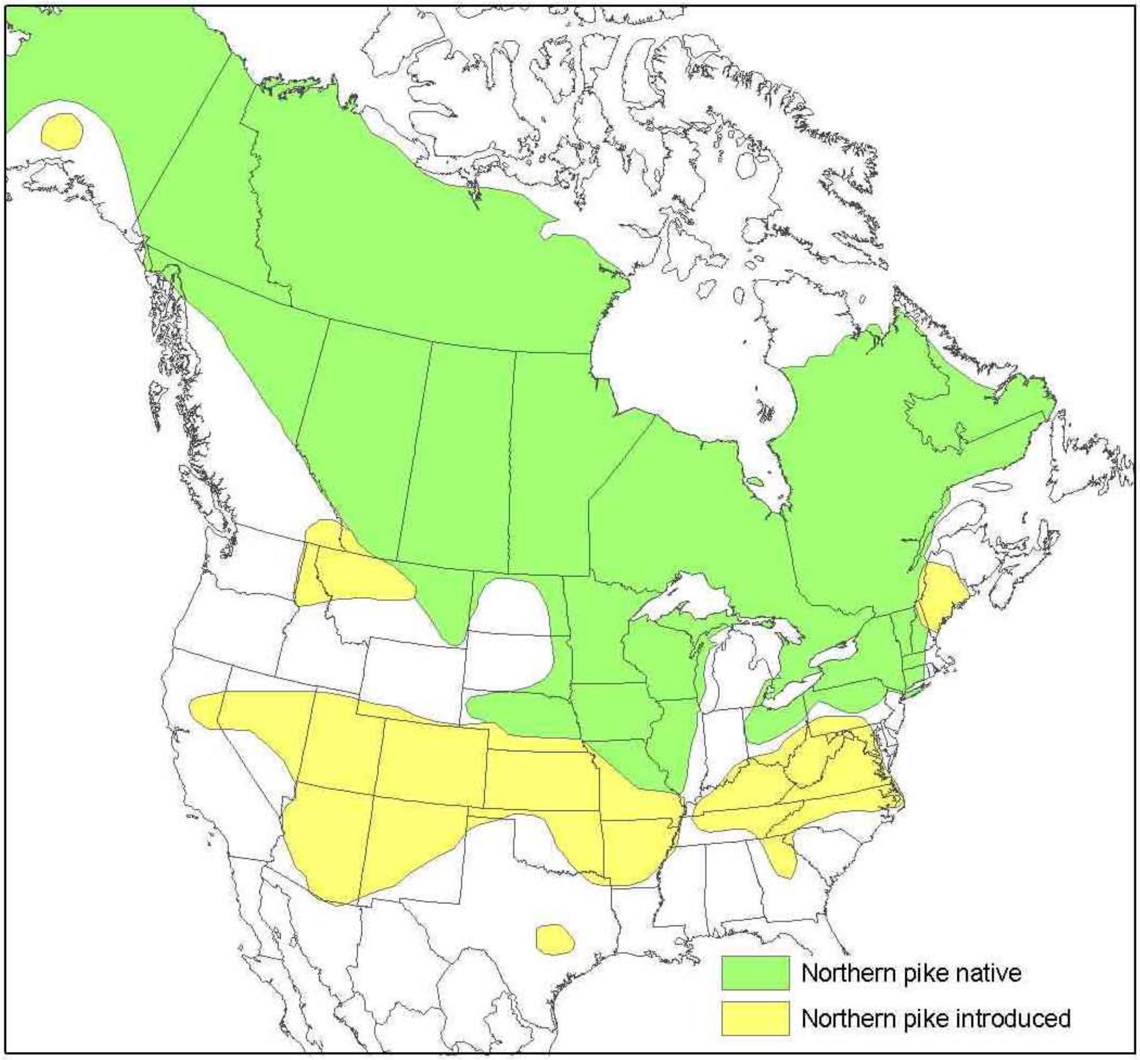

Figure 2. The North American distribution of northern pike from Bradford et al. (2008).

In British Columbia, northern pike are confined to the northeastern corner of the province contiguous with the Yukon. This includes the Peace, Liard, Yukon, Alsek, Taku and Mackenzie River systems. They do not penetrate into the Williston Lake watershed upstream of the Peace Canyon and are also absent from the Iskut-Stikine system (Carl and Clemens 1953; British Columbia Ministry of Fisheries undated). The northern extent of the species' range in Canada is noted by Ellis (1962) who records several specimens taken by gill-net in the Coppermine River delta, and quotes anecdotal Inuit use of the species even farther north, in the Igloolik area.

The variety of habitats occupied by northern pike limits the usefulness of any estimates of abundance; in Wisconsin lakes, which are likely comparable to some Canadian situations, average abundance was reported to be 16.1 adults/ha (Margenau et al. 1998).

2.3 NON-NATIVE DISTRIBUTION

In this review, the term ‘introduction’ is used in its broadest sense, namely to describe the movement of a species into any habitat other than its original one (Crossman 1991). As a perennially popular sport fish (see Section 4.1), northern pike have been introduced to waters outside its ‘native’ range for centuries; introduction into Ireland in the sixteenth century, as already noted, may simply have been the first recorded transfer. While countless transfers are un-recorded and many are illegal (Aguilar et al. 2005), some attempts have been made to pull together the extensions of the pike’s already impressive range. One such is the map created by NatureServe (2006), for American populations: the ‘historic’ distribution is little more than a thread south of the Great Lakes, surrounded by large tracts of habitat extending well into the midwestern U.S. and as far west as Montana.

Further detail on introductions within the continental United States is provided by the extensive posting for the species on the United States Non-indigenous Aquatic Species Database (Fuller 2007), which lists 119 documented transfers at locations from Alaska to Texas. Most of the introductions have been for sport fishing, not all of them legal; they have resulted in northern pike living outside their native range in 38 states. Wydoski and Whitney (2003), describe expansion of pike range within the American portion of the Columbia River system following illegal introduction into the Coeur d’Alene system in the early 1970s, a good example of the species’ ability to gradually infiltrate suitable habitat (see also McMahon and Bennett 1996 for a discussion of habitat infiltration). The spread of northern pike within south-central Alaska is more fully discussed below (see Section 5.0). Northern pike is listed as a “detrimental animal” in California, and cannot be imported, transported or possessed without a permit (Lee 1999).

Introductions within Canada are less well documented. Some have resulted in obvious impacts (see Section 5.0). In Ontario, introductions and transfers of northern pike have used wild rather than hatchery-produced fish (Kerr and Lasenby 2001); however, there is an extensive history of hatchery stocking in Saskatchewan to provide fisheries in shallow or previously unexploited waters where pike were not previously found (Marshall and Johnson 1971).

In British Columbia, northern pike are known to have been introduced into Charlie Lake, near Fort St. John (B.C. Ministry of Fisheries undated), and Crossman (1991) notes some undated authorized introductions from Yukon and Alberta into British Columbia, based on records of the Federal-Provincial Transplant Committee. The same agency also notes two approvals for transfers, in 1983 and 1985, of northern pike from the Liard River and Moon Lake, Saskatchewan, both to Wye Lake, Yukon (B. Anderson, Fisheries and Oceans Canada (DFO), pers. comm.).

The first known case of its introduction outside its native range in B.C. (that is, outside the northeast corner of the province) was in the Kootenay region in 2005, where several presumably illegally introduced northern pike were captured in Ha Ha Lake (S. Pollard, B.C. Ministry of Environment, pers. comm.). Northern pike have also recently been angled from the extreme northern end of the Koocanusa Reservoir, a large trans-boundary water body that connects with the mainstem Kootenay River (T. Brown, DFO, pers. comm.). The origin of the pike in Ha Ha Lake and the Canadian portion of the Kootenay River is unlikely to be determined without a comparative analysis of their DNA and that of putative donor stocks.

The many introductions within Europe, and from Europe to other continents, would be impossible to list, although some records have been compiled. Welcomme (1988) cites introductions into Ireland, Spain and Italy, and, farther afield, to Madagascar, Morocco, Tunisia and Uganda.

3.0 BIOLOGY AND NATURAL HISTORY

3.1 AGE AND GROWTH

Age and growth of northern pike have been intensively studied, using evidence from scales, opercula, cleithra (small pectoral bones) and otoliths (Casselman 1996). Northern pike may live as long as 30 years in the wild (Stewart and Watkinson 2004; B.C. Ministry of Fisheries, undated), although only 40% of pike populations have individuals older than 7 years (Casselman 1996). Females live longer, grow faster, and are bigger than males. Sex ratio appears to favour females in summer and winter, and males in spring and fall, but is hard to quantify because different sampling methods (netting and angling) select the sexes differentially (Casselman 1975). Anglers tend to take more females than males, because females are more active and susceptible in summer.

Juvenile northern pike grow rapidly, producing a 15 cm fish by the end of the first summer (Scott and Crossman 1973); a rule of thumb for the Great Lakes is 10 mm in length for every week post-hatch (Casselman 1996). Growth is generally slower for more northerly populations (Inskip 1982), in which sexual maturity is reached later. However, Diana (1996) notes that climate influences growth most strongly in year 1, with the effect lessening by years 3 to 5. Asian pike are the slowest-growing; European and Asian pike end up larger than those in North America (Scott and Crossman 1973).

While the average size in the small Canadian commercial fishery is 0.9 – 2.3 kg, the popularity of the species as a sport fish means that it has a number of "maximum" sizes, and there is no lack of extravagant pike lore featuring size and voracity. The largest northern pike taken in Canada is usually identified as the 19 kg fish caught in Stoney Rapids, Saskatchewan in 1954 (DFO 2006b).

3.2 PHYSIOLOGICAL TOLERANCES

Northern pike can tolerate a wide range of environmental conditions, a hardiness that makes the species relatively easy to introduce outside its native range (or too easy, depending on one's point of view). Its physiology, activity, feeding and reproduction are affected by many factors including temperature, oxygen, pH and salinity (Casselman 1996).

3.2.1 Temperature

Northern pike is a cool-water species that inhabits a wide belt of latitudes. Its southern limit appears to be temperature-imposed. Optimum temperature for growth is slightly higher for young-of-the-year (YOY) (22-23ºC), than for juveniles and sub-adults (Casselman 1996). Casselman and Dietrich (2003) report an increase in pike abundance in eastern Lake Ontario over seven decades, correlated with a significant increase in water temperature. Growth rate increases rapidly above 10ºC and is highest between 19ºC (for biomass) and 21ºC (for length); upper lethal temperature is 29.4ºC, and pike can tolerate temperatures as low as 0.1ºC (Casselman 1978).

3.2.2 Oxygen

The response of northern pike to varying levels of dissolved oxygen is reviewed by Casselman (1978), Casselman and Lewis (1996) and Casselman (1996). The species is remarkably tolerant to variations in oxygen level, surviving concentrations as low as 0.3 mg/l in shallow lakes, and having been caught alive at oxygen concentrations as low as 0.04 mg/l. Pike begin to seek higher oxygen levels at concentrations less than 4 mg/l. Feeding ceases when oxygen concentration drops below 2 mg/l. Critical oxygen concentration depends on temperature; the upper range of the lower incipient lethal oxygen concentration varies between 0.5 and 2.0 mg/l.

3.2.3 pH

Northern pike tolerate a wide range of alkalinity. Margenau et al. (1998) notes their inhabiting Wisconsin lakes at pH ranging from 6.1-8.6, while Scott and Crossman (1973) refer to a population living in a Nebraska lake at pH 9.5. Inskip (1982) mentions a population able to sustain itself at pH 5.0.

3.2.4 Salinity

While most populations of northern pike are confined to fresh waters in lakes and rivers, the species can also tolerate brackish water, notably the Baltic Sea, where it has been an important commercial species (Mann 1996). Its adaptation to the slightly saline water (around 6 ppt in the southern Baltic; one-fifth that of full seawater) is such that stocking programs using freshwater-raised fingerlings are not successful (Larsen et al. 2005). In Sweden, recruitment from natural coastal spawnings is much lower than from freshwater, possibly because of stickleback predation on eggs (Nilsson 2006). There are occasional reports of pike caught in commercial coastal fisheries; see for example Lee (1999) and Southcentral Alaska Northern Pike Control Committee (2006) for a case in Cook Inlet, Alaska. Such reports raise the possibility of pike seeding new freshwater habitat through coastal infiltration.

3.3 REPRODUCTION

Northern pike spawn in spring, shortly after the ice has melted. When the water has warmed to 8-12ºC, fish leave the still waters of the lake and migrate up tributaries to flooded marshes or shallow pools where grasses and sedges serve for cover and egg deposition (Casselman 1995).

Gonadal development for the next season's spawning begins the previous fall and continues over the winter (Lenhart and Cakic 2002). The age at first spawning is variously reported as two years (males) and three years (females) in Scotland; it may be later in more northerly populations (Treasurer 1990). The onset of first breeding depends on temperature, food availability and growth rate, and reflects size rather than chronological age (Billard 1996). Age at maturation is also affected by exploitation, and has been shown to fall when larger fish are removed from the population (Diana 1996). Northern pike mature and spawn readily in small, managed ponds.

3.3.1 Spawning behaviour, fecundity and yield

The first written description of reproductive behaviour in northern pike was probably that of Walton (1653), who noted the basic pattern of external fertilization in shallow waters into which the fish migrated to spawn. More recent observations suggest participation of several males per female, with many matings over a period of several days (Scott and Crossman 1973; Billard 1996). Spawning congregations can be impressive; Scott and Crossman (1973) cite one instance of 6,000 fish in a creek in Saskatchewan in the 1950s.

Females scatter the eggs in small batches (less than a hundred), which sink and stick to vegetation or the bottom, hatching around two weeks later without parental care (Billard 1996). Hatching success is higher in eggs deposited on sand or silt, compared with those laid on aquatic plants (Wright and Shoesmith 1988). Fecundity increases with size of the female; Inskip (1982) cites an average fecundity of 32,000 eggs per female, although much larger numbers have been reported. Fecundity for several populations of pike in the British Isles varied between 10-24 eggs/g (Treasurer 1990). Even within quite restricted geographic boundaries (all the pike in a reservoir, for example), fecundity is highly variable, depending not only on size of the female, but also on temperature, food availability, social interactions and density (Billard 1996). While bigger females produce bigger eggs, the average size of the month-old fry is the same; genetic and environmental factors — primarily water level and temperature — appear to affect growth and survival more than egg and larval size (Craig 1996).

The projected distribution and yield of northern pike have been studied in relation to anticipated increase in annual temperature (Minns and Moore 1992). High, stable water levels through fry development produce larger year classes (Johnson 1957), as do higher summer temperatures (Craig 1996). Egg-to-fry survival is around 70%, but the number actually making it to fingerling stage can be as low as the .037% reported in the Riviere aux Pins, Quebec (Masse et al. 1993).

Artificial fertilization in hatchery conditions affords much higher egg survival. Billard (1996) reviews the literature on incubation and hatching under controlled conditions, providing many useful insights into the tolerance of developing ova to temperature, oxygen concentration and physical shock.

Newly hatched larvae are 6-8 mm long. They swim upward and attach vertically to available substrate during yolk absorption (a period of 6-10 days) by means of a nasal adhesive gland (Bry 1996). Oxygen exchange is through the body surface until gills develop, so some water movement is necessary (Braum et al. 1996). Once the nasal gland regresses, the 12-15 mm larvae swim to the surface, fill their swim bladders with air and begin to feed.

3.4 FEEDING AND DIET

The voracity of northern pike has long been known; Walton (1653) notes that “their life is maintained by the death of so many fish.” The ability of the species to consume impressive quantities of prey is also remarked upon by most modern reviewers; Scott and Crossman (1973), for example, cite a report of 2,594 pike eating more than 112 tons of fish in a year. Regarding the actual mode of feeding used by northern pike, Casselman (1995) describes a crepuscular, ambush style of predation that relies on camouflage within aquatic vegetation. While the abundance of prey affects growth rate, it is not usually critical to survival, because pike are opportunistic feeders, switching to invertebrates and even each other when fishes are scarce (Casselman 1995).

The energetics of northern pike — quantitative analysis of its diet and the metabolic uses to which that diet is put — have been extensively studied; bioenergetic models help describe the species’ ecosystem interactions, especially its interactions with prey. Diana (1996) reviews assumptions and performance of a variety of these models for pike.

3.4.1 Juvenile diet

Once the yolk sac is absorbed, young pike feed on aquatic zooplankton for 7-10 days before turning to aquatic insect larvae and then to fishes, which predominate by the time young are 5 cm long (Scott and Crossman 1973). The general temporal sequence of prey is: micro-crustaceans (e.g. cladocerans), insect larvae (e.g. chironomids), macro-crustaceans (e.g. asellids), then fishes; the presence of aquatic vegetation in the nursery areas where young pike feed is critical to the production of invertebrate prey (Bry 1996).

3.4.2 Adult diet

Northern pike adapt to the available food, and several authors caution against declaring absolute preferences (Broughton 2001). In North America, the primary prey of adult northern pike is probably yellow perch *Perca flavescens*, with opportunistic use of invertebrates when fishes are unavailable (Chapman and Mackay 1990; Venturelli and Tonn 2005). Pike will also take leeches, frogs, crayfishes, mice, muskrat and ducks, with an optimum prey size one-third to one-half the pike's body length (Crossman 1973). Diana (1979) noted a peak in feeding in June, and a spawning 'fast' in late April; the prey taken (in this case, Lac Ste. Anne, in Alberta) were, in order of numerical importance, perch, spottail shiner *Notropis hudsonius*, burbot *Lota lota* and white sucker *Catostomus commersoni*. Feeding opportunity, not prey size, determined what the fish ate; females ate more than males. Inskip (1982) reviews the wide variety of prey used by northern pike, as well as their propensity for cannibalism as juveniles and adults when there is not a great diversity of available prey. Cannibalism appears to be a natural population control mechanism (Craig 1996; Mann 1996).

Seasonal changes in temperature and day length combine to produce a shift in feeding patterns: during winter, pike are more active and feed during the day, a reversal of the summer crepuscular pattern (Casselman 1995).

3.5 HABITAT REQUIREMENTS

Habitat requirements for northern pike are reasonably well-defined (Casselman and Lewis 1996) and were extensively reviewed by Inskip (1982), who used the published data to provide a comprehensive habitat suitability index (HSI) model for the species. Northern pike are generally found in shallow, moderately productive, vegetated waters less than 4 m deep, a preference that concentrates them in the near-shore zone. While commonest in mesotrophic or borderline eutrophic lakes, northern pike may also be found in rivers; however, they avoid fast water and seek out vegetated side channels, sloughs and other backwaters - in other words, lake-like habitat. The lacustrine and riverine HSI models for northern pike developed by Inskip (1982) are very similar.

3.5.1 Water depth

Highest adult densities are usually recorded in shallow water with penetrable vegetation (Chapman and Mackay 1990). Favourable water levels also affect reproductive success (Dumont et al. 1977), and northern pike abundance has been deliberately increased in some areas of Ontario by introducing broodstock into 'managed marshes' where water level can be optimized (Kerr and Lasenby 2001). Inskip (1982) reviews the dependence of northern pike on water level, and notes how year-class strength reflects water level fluctuation, and that depth distribution within the water column probably reflects a balance of optima including temperature, dissolved oxygen, vegetation and food, with northern pike rarely occurring below the thermocline.

3.5.2 Changes in habitat preference with life stage

Bry (1996) reviews the critical role of aquatic plants in the pike life cycle: for spawning, egg adhesion, fry support during yolk sac absorption, provision of prey for fingerlings, and cover for adults. Once pike are mature, they can occasionally be found in un-vegetated areas, but only outside the spawning period. Spawning habitat in rivers includes low-gradient pools and marshy areas; pike that stay in lakes to spawn seek out littoral zones, ditches and small tributaries. The common factors are vegetation, shallow water, absence of current and protection from winds. The critical role of vegetation, which provides cover for adults, attachment for eggs and larvae, and food and cover for juveniles, is emphasized by many reviewers (for example, Casselman 1995; Casselman and Lewis 1996; Billard 1996; Bry 1996), and it is not surprising that one successful technique for enhancing natural production of pike is to create managed spawning marshes with ample vegetation (Kerr and Lasenby 2001). A lack of suitable vegetation can inhibit spawning (Inskip 1982).

The abundance and variety of the aquatic invertebrates that are the first food of pike fry depend on the kind and amount of aquatic vegetation. Bry (1996) reviews studies linking aquatic plants, aquatic invertebrates and pike fry. YOY require dense vegetative cover (for concealment); this stage seeks out floating and submergent vegetation that provides 40-90% cover. Preferred depth increases with growth; Casselman (1995) provides a rule of thumb of 10 cm in depth for every week.

As northern pike mature, their preference for water depth and type of aquatic vegetation changes, but the critical importance of aquatic macrophytes remains. Adults are usually found in clear water in summer, with at least 30% submerged macrophyte cover (Casselman 1995). Larger fish, including females, are found deeper, occasionally in un-vegetated waters (Chapman and Mackay 1984); lakes with very dense vegetation usually have smaller pike (Grimm and Backx 1990). Findings like these, as well as results of radio-tagging studies and investigation of habitat changes that have led to declines in pike populations, led Bry (1996) to conclude that the dependence on aquatic vegetation was a constant factor in the life of northern pike, decreasing only for large fish, outside the spawning period.

A quantitative model for pike habitat requirements as a function of life stage suggested that spawning habitat was actually less limiting than feeding habitat for fry, juveniles and adults (Minns et al. 1996), a conclusion borne out by observations in the field (Casselman and Lewis 1996).

3.6 INTERSPECIFIC INTERACTIONS

As a top predator, northern pike's ecosystem role is mostly that of a consumer. However, northern pike eggs and young are also eaten by other fishes, waterfowl, mammals and even invertebrates; Bry (1996) reviews the evidence for predation on pike larvae and juveniles by large aquatic invertebrate larvae, chiefly *Dysticus* (water beetle) species that hide in aquatic vegetation. Adults are taken mainly by man, with occasional capture by other animals during spawning in shallow water.

For the purposes of this biological synopsis, the most important interspecific interactions are those between northern pike and its prey and competitors. Such interactions are the biological basis for any assessment of the impact of introductions of northern pike, and are discussed below (see Section 5.0).

3.7 BEHAVIOUR AND MOVEMENTS

While pike are quite tolerant of a wide range of temperature and oxygen concentration, they do move within the water column in response to changes in these parameters. In summer, adults move to deeper, cooler water. In winter, they approach the ice-water interface as oxygen decreases, and stop feeding in winter when oxygen drops below 2 mg/l (Casselman 1995). Swimming is maximal at around 20ºC; northern pike are less active below 6ºC (Casselman 1978; Kendall 1978).

For most of the year, pike appear to be sedentary and vaguely territorial. Transmitters implanted in northern pike in Lac Ste Anne, Alberta recorded activity only 20% of the time (Diana 1980), scientific confirmation for its characterization as an "ambush predator" perfectly adapted to exploding suddenly out of concealment. The pike in Lac Ste Anne were inactive at night (Diana 1980).

3.7.1 Spawning migrations

Scott and Crossman (1973) and Lee (1999) allude to reports of spring spawning migrations but do not provide details. Inskip (1982) reviews the evidence for spawning migrations and reports tagging studies in Missouri that show pike traveling tens of kilometers, occasionally hundreds, to spawn in tributary streams; as expected from the species' preference for still or slow-moving waters, currents stronger than 1.5 m/sec inhibited movement. Homing to particular spawning grounds did not seem to occur. Mann (1996) reviews other tracking studies that suggest considerable variation in the length of migrations, even within populations.

3.8 PARASITES, DISEASES AND CONTAMINANTS

Northern pike is a species of great interest to fish pathologists. Its parasites are legion, representing fungi, protozoa, various worms, leeches, molluscs and crustacea. Pike are also susceptible to numerous bacterial and viral diseases, tumorous lesions and the bioaccumulation of environmental toxins. The long list of parasites probably reflects the great flexibility in the diet of northern pike; their interaction with northern pike is comprehensively reviewed by Dick and Choudhury (1996).

Watson and Dick (1980) identified 18 species of metazoan parasite on northern pike in Manitoba. Common parasites include the trematode worm *Uvulifer ambloplitis*, which forms external cysts, and the nematode *Raphidascaris acus* in the gastrointestinal tract and liver (Poole and Dick 1986). The common bacterium *Pseudomonas hydrophila* causes muscle necrosis (Scott and Crossman 1973).

3.8.1 Viral diseases

Of great interest to anglers and oncologists is a malignant lymphoma remarkably to similar to lymphomas in man and occurring as transient epizootics that can affect one of every eight fish (Mulcahy 1982). Its overall frequency of 20.9% is the highest known frequency of a malignant neoplasm in any vertebrate. The disease, which is not transmitted to man, is distributed globally through northern pike and is thought to be caused by a virus (Papas et al. 1976). It may also be transmitted to muskellunge-pike hybrids (Bowser et al. 2002). Other viruses include the herpes virus that causes blue spot disease (Margenau et al. 1995; Graham et al. 2004) and the oncovirus causing dermal sarcoma (Dick and Choudhury 1996).

The most serious viral infections of pike are seen in cultured fish in Europe (Dick and Choudhury 1996). Of some practical importance is the rhabdovirus that causes viral hemorrhagic septicemia (VHS) in fishes, a disease primarily associated with farmed salmonids but also found in northern pike hatcheries. VHS virus has also been identified in wild northern pike in Europe (Enzmann et al. 1993); a North American strain of the VHS virus has recently been identified in wild pike and muskellunge in Michigan (World Animal Health Organization 2006). It is not clear whether wild populations are being infected by captive ones, as the wild pike virus is not infective in rainbow trout (McAllister 1990); however, the possibility of transmission is relevant to any introductions.

3.8.2 Bioaccumulation of environmental toxins

Northern pike share with many top predators a vulnerability to environmental contaminants that accrue in the food chain. Garcia and Carignan (2000) reported that methyl mercury concentrations in pike from 20 boreal lakes in the Canadian Shield exceeded the World Health Organization's advisory limit for human consumption; the highest concentrations were in logged lakes, where pH was lowest. Methyl mercury in northern pike in Ontario is discussed by Wren et al. (1991); a comprehensive review of Canadian standards for human consumption is provided by Environment Canada (2002).

Bioaccumulation of organochlorines, including PCBs and DDT, by northern pike in subarctic Yukon lakes was reported by Kidd et al. (1998), who discuss the effects of muscle lipid content and food chain position.

4.0 USE BY HUMANS

4.1 COMMERCIAL FISHING

Modest commercial fisheries for northern pike have historically been important in several countries and are best documented in the former USSR and Finland (Mann 1996). In Canada, commercial harvest of northern pike has been mainly from the Great Lakes, Manitoba and Saskatchewan. The Great Lakes fishery declined from a high of 1.6 million kg/yr at the turn of the century to less than 0.05 million kg by the late 1960s, as near-shore spawning and nursery wetland were lost to development (Casselman 1995). Reported commercial catches in the Great Lakes have hovered near zero since closure of the fishery during the 1970s in response to mercury contamination (Baldwin et al. 2002). The present commercial fishery for northern pike in Canada is relatively small. The Freshwater Fish Marketing Corporation, a Canadian Crown Corporation marketing freshwater fish product from Manitoba, Saskatchewan, Alberta, Northwest Territories, and part of Northwestern Ontario, took delivery of 1,200 metric tonnes of northern pike in a 12 month period in 2006 and 2007 (Ellen Smith, Freshwater Fish Marketing Corporation, pers. comm.). There are small subsistence fisheries in some parts of its range, including the Mackenzie River delta (Howland et al. 2001).

4.2 RECREATIONAL FISHING

As its lengthy chapter in *The Compleat Angler* would suggest, northern pike is a perennially popular sport fish. Recreational angling is overwhelmingly the number one reason for northern pike's introduction outside its native range in North America and Europe; angling now far outweighs commercial fishing for the species.

Unlike the larger muskellunge, northern pike are relatively easy to catch. One trout angler relates inadvertently hooking a pike on a back-cast in an Alaskan river delta at 3 AM, neatly confirming the species' willingness to take any moving lure, its habit of crepuscular feeding, and (because the angler was standing facing away from a quiet-water slough) its habitat preferences (D. Anderson, pers. comm.).

Pike angling is heavily promoted in Europe and North America; in Canada, lakes in Ontario, Quebec and Saskatchewan are especially popular, and promotional websites suggest that fish that are caught are often released. Winter feeding, although reduced, means they are still a target for ice fishing.

4.3 AQUACULTURE

Pike culture developed in Europe during the 1970s, primarily as a source of fingerlings to be used to stock water bodies for recreational fishing, although the Finnish commercial pike fishery has also benefited from stocking (Mann 1996). The technologies for gamete collection, artificial fertilization and rearing using pelleted diets are well-developed, although the species cannot be considered domesticated (Billard 1996). While there are now pike hatcheries in North America, research remains most intense in France and Eastern Europe and includes studies in masculinization of fry, feed composition and cryopreservation of gametes to preserve genetic heterogeneity (Schmel and Graham 1986; Demska-Zakes et al. 2000; Kucska et al. 2005). FAO aquaculture statistics for northern pike point to highest production in France, Belarus, Czech Republic and Hungary, although production is well off the peak attained in the mid-1990s (FAO 2003).

In North America, hatchery production of esocids has been dominated by muskellunge and hybrid tiger muskellunge; technology for muskellunge was first reported in Ontario in 1927 (Kerr and Lasenby 2001). As in Europe, hatchery production is primarily for recreational fishing, either by supplementation of existing populations or transfer of the species to habitats where they had not existed before. The latter practice has been highly successful for muskellunge, with nearly one-quarter of Ontario's muskellunge lakes created through authorized introductions (Kerr and Lasenby 2001).

5.0 IMPACTS ASSOCIATED WITH INTRODUCTIONS

The impacts of introduced aquatic organisms have been grouped in five categories: habitat alteration, trophic alteration, spatial alteration, gene pool deterioration and disease introduction (Kohler and Courtenay 1986). Taylor (2004) points also to the more general 'homogenization' where regional faunas become more similar to each other (this is also called 'faunal similarity'). For northern pike, the most important impact is trophic alteration or re-structuring of fish communities. Northern pike have also been introduced to control exotic species, notably common carp *Cyprinus carpio,* in several American states (USFWS 2005).

The most frequently introduced fish species in Canada are the same as those in the U.S.: common carp, brown trout *Salmo trutta*, goldfish *Carassius auratus*, rainbow trout *Oncorhynchus mykiss* and smallmouth bass *Micropterus dolomieu*. So too are the reasons for their introduction: for recreational angling, for aquaculture and through accidental releases from aquaria (Taylor 2004). While introductions of northern pike in Canada do not approach the levels of these five species, their impacts can now be predicted, qualitatively if not quantitatively.

In Canada, northern pike introductions are more commonly range extensions; that is, fish are introduced into waters contiguous to their native range. Transfers over larger distances have, however, occurred. Whatever the distance involved, once introduced to a new habitat, northern pike disperse naturally, taking advantage of whatever pathways exist (Kerr and Lasenby 2001). The literature on their introduction thus contains numerous examples of their spreading throughout interconnected lake and river systems, such as that in the extensive Susitna River drainage in Alaska (South-central Alaska Northern Pike Control Committee 2006). Other examples include their spread within the Saskatchewan River drainage in Montana (Dos Santos 1991), and their migration through the Trent Canal system in Ontario, resulting in extension of their range to Kawartha Lakes and subsequent reduction in numbers of muskellunge *Esox masquinongy* (DFO 2006a).

5.1 Trophic effects on other fish species

The most frequently studied impacts of northern pike in a new habitat are those on fish communities including prey (such as minnows and perch) and competitors (such as muskellunge). Unfortunately the reports of these ecological effects are often anecdotal or based on inferences from studies of diet preferences. For example, while there is concern about extension of the pike's range to Kawartha Lakes by way of the Trent Canal system in Ontario, and there is evidence for reduction in numbers of muskellunge *Esox masquinongy* (DFO 2006a), quantitative data are not extensive.

Findlay et al. (2000) discuss some of the challenges of experimental design and interpretation peculiar to studies of the impact of piscine predators, in the context of their research on the effects of introduced piscivores on minnow populations in Adirondack lakes. These authors note that prey species — such as the minnows they studied — can be affected not only by piscivores but also by other factors correlated with the presence of piscivores; examples include minimum dissolved oxygen, periodic dissolved oxygen deficits, trends in acidification, maximum summer temperatures and availability of spawning habitat. The number of variables measured and included in any such study thus becomes critical to its interpretation. The ecosystem interactions are sufficiently complex to make control efforts difficult to design: Mann (1996) reviews a number of studies in which selective pike culls actually backfired, by removing an intraspecific source of population control.

5.1.1 Interactions with prey fish species

Most research on the interaction between northern pike and other species concentrates on its effect on prey fish communities, although Venturelli and Tonn (2005), in a study of pike deliberately introduced to a Canadian boreal lake, showed that northern pike can affect littoral macro-invertebrates as well. However, it is the consumption other fish that forms the basis of most investigations of the impact of northern pike.

Kerr and Lasenby (2001), in their annotated bibliography of esocid stocking, review the international literature documenting impacts on prey species. These impacts include decreased cyprinid densities (Ontario lakes); decreased yellow perch (Wisconsin); declines in brown trout (Ireland); reduced abundance of native prey fishes (Spain); and reduced yellow perch, walleye and bass (Minnesota). Pike have been shown to consume migrating Atlantic and Pacific juvenile salmonids (see Southcentral Alaska Northern Pike Control Committee 2006 for a review of evidence for Russia, Denmark and Alaska); however, the evidence is often anecdotal. In warmwater lakes in Nebraska, northern pike were shown to structure perch and bluegill communities (Paukert and Willis 2002).

The wide range of effects in the studies cited above is consistent with pike's ability to feed opportunistically, adapting to whatever prey is available. As already noted for reports of interspecific interactions, data are sometimes lacking or hard to interpret; the study from Spain, for example, notes that the native species whose numbers declined after pike introduction appeared headed for extinction for other reasons (Elvira 1998). A more tightly controlled study of the vulnerability of cyprinids compared Adirondack lakes with and without introduced piscivores (including northern pike), and showed native minnow richness to be reduced by two-thirds in lakes with piscivores (Findlay et al. 2000). In this study, nonnative (ie introduced) minnow-like species were less affected. The authors review a number of other studies, including several for lakes in Quebec and Alberta, that confirm the vulnerability of native minnow assemblages, and argue for strict controls on piscivore stocking.

5.1.1.1 Interactions with salmonids

There are numerous reports of the detrimental effects of introduced northern pike on salmonids. Effects on sport fisheries for trout have been reported for a variety of systems in North America (McMahon and Bennett 1996) and Europe (Broughton 2001). Aguilar et al. (2005) cites predation on stocked trout in Lake

Davis, California, where illegal introduction of northern pike has been well studied and where there is also a threat to the native chinook salmon *Oncorhynchus tshawytscha* in nearby watersheds. Northern pike may also be involved in the decline of native cutthroat trout *O. clarki lewisi*)and bull trout *Salvelinus confluentus* in Montana (McMahon and Bennett 1996; Muhlfeld et al. 2008).

Perhaps the most exhaustive assessment of the potential impact of pike introductions on salmonids is in Alaska. The Southcentral Alaska Northern Pike Control Committee (2006) has reviewed the issue, and the following discussion is based on their report. The chief concern is predation on natural and supplemented populations of Pacific salmon *Oncorhynchus spp*., which could have both economic and ecological consequences given the salmon's position as a keystone species that acts not only as a consumer of prey but also as food for mammals and birds, as well as a supplier of nutrients to terrestrial ecosystems. Rainbow trout maintained in many Alaskan lakes by annual stocking programs are also believed vulnerable to predation by illegally introduced northern pike.

In Alaska, the main problem is introductions outside the pike's native range (the species occurs naturally throughout much of the state), and the authors of the Alaskan report cite anecdotal reports of pike appearing in freshwater salmonid rearing habitat and lakes. A good example is the Kenai River system, where illegal introductions in tributaries have resulted in infiltration of many small lakes and streams; pike are now believed to use the mainstem river as a migratory corridor. There are even reports of their being caught by commercial fishermen in Cook Inlet, suggesting more widespread dispersal.

5.1.2 Interactions with competitors

While northern pike and its relative muskellunge have somewhat different habitat preferences, they often occur together, either naturally or by human design. Northern pike spawn earlier, grow faster, and convert food better than muskellunge; they also eat young muskellunge, and tend to out-compete them for food and spawning sites whenever the two species occur together (Scott and Crossman 1973). Kerr and Lasenby (2001) cite several reports that suggest an inverse relationship between pike abundance and muskellunge spawning success. For example, Dombeck et al. (1986) found successful reproduction of muskellunge to be inversely correlated with pike abundance; in keeping with the caveats on experimental design already discussed above, it is worth noting that a number of abiotic variables affected muskellunge reproduction in this study as well.

The pike's relationships with walleye and largemouth bass are similar, if less clear, probably because the three species prefer different environments within lakes (Craig 1996). For example, pike may compete with walleye by predation on northern perch in some northern Ontario lakes (Krishka et al. 1996), although the two species appear to coexist harmoniously in other lakes. The complexity of such ecosystem relationships suggests that any introduction of northern pike be carefully evaluated (Kerr and Grant 2000).

5.2 GENETIC EFFECTS

One relatively unnoticed effect of introduction and transfer of northern pike in North America, especially by stocking, may be further genetic homogenization of an assemblage of populations that were quite similar genetically to begin with (Taylor 2004; Aguilar et al. 2005).

Microsatellite DNA analysis is now being widely used to study introgression between wild and introduced stocks, as has, for example, occurred with French populations restocked with fish from local or Eastern European hatcheries (Launey et al. 2006). Where introgression seems not to have occurred, as was shown in one study in Norway, other explanation for poor performance of stocked fry need to be sought (Larsen et al. 2005). As nuisance populations of northern pike become more common, this forensic application of microsatellite DNA has great practical value. A recent study by Aguilar et al. (2005) used the tool not only to narrow down source populations of pike illegally introduced into Lake Davis, California (a notorious example of a potential ecological threat to a large watershed), but also to search for the genetic signatures of recent population bottlenecks and demonstrate that rotenone treatment to eradicate pike had not been successful.

The northern pike genome has been successfully manipulated not only by introductions and glaciations, but also by deliberate crosses and gene transfers. The cross between northern pike and muskellunge produces the ‘tiger muskellunge’ which is stocked in some North American lakes for sport fishing. Despite different habitat preferences for the two species, hybridization can even result naturally when northern pike are introduced into waters containing native muskellunge; some female hybrids are fertile and capable of back-crossing (Becker 1983). Culture of northern pike for stocking means there are now hatchery-bred strains, such as the ones studied in France by Launey et al. (2006).

Northern pike even qualifies as a genetically modified organism (GMO): growth rate has been increased by microinjection of growth hormone genes (Gross et al. 1992). If introduction of pike outside its native range is a concern, the existence of manipulated strains must clearly be considered.

5.3 POSSIBLE DISEASE TRANSMISSION BY HATCHERY-RAISED PIKE

Kerr and Lasenby (2001) cite reports of hatchery pike affected by a number of parasites and pathogens, including lymphosarcoma. Transmission of this or any other disease between pike and other fish species is difficult to predict or prove, but it does constitute a potential impact.

5.4 IMPACT SUMMARY

The main impact of northern pike introduced outside its native range is alteration of fish communities through predation and competition. Hybridization with other esocids is a secondary concern, as is the possibility of disease transfer from wild and hatchery-produced stock.

As an opportunistic feeder, northern pike is capable of restructuring existing prey fish communities, with effects especially well-documented for cyprinids (minnows). They will compete with muskellunge for food and habitat. The quantitative impact of predation on salmonids, which is the most frequently voiced concern regarding introductions, is less well documented, but can include not only landlocked species like trout (which may themselves be native or introduced), but also sea-run species of Pacific salmon (which may include not only wild stocks but also enhanced ones).

Widespread stocking of northern pike, whether for recuperating native populations or providing sport fishing opportunities, may result in genetic homogenization and could potentially introduce parasites and diseases.

6.0 CONSERVATION STATUS

Northern pike ‘conservation’ is something of a paradox. As an introduced species, pike provokes concerns about ecosystem impacts. But as a native keystone piscivore, it is as vulnerable, if not to fishing, then certainly to habitat loss, as any other freshwater fish. Human development in the Great Lakes region, for example, has taken its toll on northern pike populations, depriving pike of critical wetland habitat (Casselman and Lewis 1996). Restoration of native pike habitat is a goal throughout its global range, and the efforts to supplement native pike populations with hatchery-raised fish have already been mentioned (Kerr and Lasenby 2001).

Genetic research on what may be distinct populations has not proceeded far enough to make arguments for their special status. The IUCN Red List refers to northern pike only as ‘not evaluated;’ in North America, where many native populations are benefiting from some form of conservation measures, neither the Canadian Species at Risk Act (SARA) Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or the U.S. Endangered Species Act (ESA) lists the species.

7.0 SUMMARY

Northern pike *Esox lucius* is a cool-water keystone piscivore whose distribution is circumpolar in North America and Eurasia. In Canada, pike are absent in the Maritimes and most of British Columbia but otherwise widespread. While most populations of northern pike are confined to fresh waters in lakes and rivers, the species can tolerate a wide range of environmental conditions, including brackish water. This hardiness makes it relatively easy to introduce outside its native range. The present synopsis provides biological background for evaluating the risk posed by introductions and transfers of northern pike in Canada. As a native keystone piscivore, northern pike is as vulnerable to habitat loss as any other freshwater fish species; however, it is nowhere considered threatened.

Northern pike is a popular summer and winter sport fish and has been introduced to waters outside its 'native' range for centuries; countless transfers are un-recorded and illegal. Introductions within Canada have used both wild and hatchery-produced fish; some have resulted in documented impacts. The first known case of its introduction outside its native range in B.C. was in the Kootenay region in 2005, where several northern pike were captured in Ha Ha Lake.

Northern pike are generally found in shallow, moderately productive, vegetated waters less than 4 m deep; they are thus most common in lakes and slower-moving rivers. Pike are ambush predators that rely on camouflage within aquatic vegetation and have a legendary ability to consume impressive quantities of prey, which can include not only fish but also frogs, invertebrates and the occasional mammal. For most of the year, pike are sedentary and vaguely territorial, although they may make short upstream spawning migrations. Its parasites are legion, representing fungi, protozoa, worms, leeches, molluscs and crustacea. Pike are also susceptible to numerous bacterial and viral diseases, tumorous lesions and the bioaccumulation of environmental toxins.

The present commercial fishery for northern pike in Canada is insignificant. Desirability as a sport fish is the main reason for introduction outside its native range in North America and Europe. In Canada, northern pike introductions are more commonly range extensions; that is, the fish are introduced to waters contiguous to their native range. The main impacts are alteration of fish communities through predation (for example, on cyprinids or salmonids) and competition (for example, with muskellunge). Hybridization with other esocids is a secondary concern, as is the possibility of disease transfer from wild and hatchery-produced stock. Widespread stocking of northern pike may result in genetic homogenization. The two methods most commonly used to control unwanted northern pike populations are culls and poisoning with rotenone.

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The northern pike (Esox lucius L.), an important predatory freshwater species, is undergoing significant population decline. In this study, 18 novel polymorphic microsatellite loci were isolated and used for assessing genetic variation in the Chinese Ulungur and Hungarian Balaton populations of the species.Â Fish assemblages that include northern pike Esox lucius as a dominant predator were sampled in 19 small (<120 ha) northern Wisconsin lakes. The purpose of this sampling was to describe northern pike population characteristics and identify factors affecting growth rates. Fish assemblages in these lakes were dominated by centrarchids, primarily bluegill Lepomis macrochirus, and small fusiform species such as yellow perch Perca flavescens.