*Esox lucius*: Northern pike

Shannon Hennessey

FISH 423 Aquatic Invasion Ecology

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Diagnostic information

Scientific name
Order: Esociformes
Family: Esocidae
Genus: Esox
Species: E. lucius

Common names: Northern pike, pike, jackfish, grand brochet

Basic identification key

The Northern pike *Esox lucius* can be characterized by a long body with a ‘duck bill’ snout, a large mouth with many sharp teeth, and cheeks that are completely scaled. The dorsal and anal fins are set posteriorly on the body with a narrow caudal peduncle and a mildly forked caudal fin. *E. lucius* have greenish dorsal and lateral surfaces with yellow bars or rows of spots running along the sides, and a whitish ventral surface (Figure 1). Body lengths range from 46-51 cm on average, with an average weight of 1.40 kg (Morrow 1980). However, in the United States these fish can grow to sizes up to 1.5 m long with weights up to 35 kg.

Life history and basic ecology

Life cycle

*Esox lucius* has a relatively simple life cycle, in which they have 4 life stages as defined by Inskip (1982), all of which have specific habitat requirements. The embryo stage is when the fish has not yet emerged from the egg. Immediately after hatching, these become fry until they assume adult proportions at a size of approximately 6.5 cm (Franklin and Smith 1960). Juveniles are defined as those fish from 6.5 cm in length to the onset of sexual maturity, or the stage at which their gonads begin to develop. Once these fish have reached sexual maturity, they become adults until the end of their life cycle. These fish are typically solitary and highly aggressive (Craig 2008).

Spawning occurs during the spring flood soon after ice-out, when water temperatures are 8-12°C and can last from a few days to more than a month (Franklin and Smith 1963, Inskip 1982, Casselman and Lewis 1996). *E. lucius* migrate up tributaries and spawn in calm, shallow waters of wetlands or flooded marshes where there are mats of submerged vegetation. This
vegetation is essential not only to the survival of the eggs, but will also become important nursery habitat once the juveniles have emerged (Casselman and Lewis 1996, Mingelbier et al. 2008). Eggs are deposited where they then stick to the vegetation mats, which suspend them off of the potentially anoxic sediments until hatching approximately two weeks later (Franklin and Smith 1963, Casselman and Lewis 1996). Water level is a very important factor in embryo survival, due to the fact that *E. lucius* usually spawn in water as shallow as 0.1 – 0.2 m deep (Inskip 1982). High water levels during spawning can also be associated with larger juveniles as the high waters bring an influx of nutrients, increasing the productivity in areas where larval fish are growing (Johnson 1957, Casselman and Lewis 1996).

Once the eggs hatch, young-of-the-year fish remain among the submerged vegetation, which provides important nursery habitat. At hatching, these fish are 7-9 mm in length on average (Frost and Kipling 1967, Forney 1968, Inskip 1982). During the first few days, fry remain attached to the vegetation until their yolk sac was absorbed (Frost and Kipling 1967, Inskip 1982). The juveniles grow rapidly, increasing their size and activity, and the shelter provided by the vegetative cover helps enhance survival (Casselman and Lewis 1996). As they grow, juveniles move to more floating and submergent vegetation, rather than the emergent vegetation preferred by fry, but remain in shallow waters (Casselman and Lewis 1996, Craig 2008).

Maturation is highly dependent on growth rate, with males typically maturing at 34-42 cm total length and females at 40-48 cm (Frost and Kipling 1967; Priegel and Khron 1975). In the US, both males and females typically mature at about 2 years of age, although there is variation due to differential growing conditions (Inskip 1982). *E. lucius* can live as long as 24 years, but longevity is also strongly correlated with growth rate (Miller and Kennedy 1948). At the more southern end of their distribution, these fish may only live up to 4 years. (Buss and Miller 1961, Schryer et al. 1971, Inskip 1982). Adults are also strongly associated with vegetation and shallow waters, showing a preference for submergent vegetation as it facilitates optimum foraging efficiency (Casselman and Lewis 1996, Craig 2008).

**Feeding habits**

*E. lucius* is characterized as a keystone piscivore that can shape the composition, abundance and distribution of fish communities (Craig 2008). They are visual predators that are primarily active during the day, feeding on a wide variety of prey from invertebrates to fishes (Polyak 1957, Carlander and Cleary 1949, Casselman and Lewis 1996, Craig 2008). As opportunistic feeders *E. lucius* will feed on prey that is seasonally abundant, although the size of their prey is limited by both their size and the size of their prey (Craig 2008). They can consume a wide range of prey sizes, but have also been shown to be size-selective predators...
Although they can be cannibalistic, this has not been shown to comprise a large portion of their diet (Frost 1954, Lawler 1965, Mann 1976). Aquatic vegetation is particularly important for feeding as these fish utilize and ‘ambush’ style of predation (Inskip 1982, Casselman and Lewis 1996). Intermediate vegetation densities have been associated with optimum predation efficiency (Craig and Black 1986), and calm, clear waters provide better visibility associated with more efficient prey capture (Craig 2008). Fry begin feeding once they reach a length of approximately 10-12 mm in length, about 10 days after hatching (Franklin and Smith 1963). They initially feed on zooplankton, but soon begin to feed on aquatic insect larvae and fish, marking the start of piscivory very early in their life (Hunt and Carbine 1951, Frost 1954, Inskip 1982). Within 4-5 weeks after hatching, at a length of approximately 50-60 mm, their diet is comprised mostly of fish, and fry as small as 21 mm have been shown to be cannibalistic (Hunt and Carbine 1951). As they continue to grow, their prey is predominantly fish, although they have been known to prey on crayfish, waterfowl and even small mammals (Frost 1954, Lagler 1956, Seaburg and Moyle 1964, Lawler 1965, Mann 1976, Inskip 1982).

Reproductive strategies

*E. lucius* is an iteroparous species, undergoing multiple reproductive events, with a relatively high fecundity. These fish form spawning groups, usually consisting of one female and either one or several males. 5-60 eggs are released at any one spot, where they are then fertilized by males (Svardson 1949, Clark 1950). The gametes are broadcasted, with no parental care provided post-spawning (Eddy and Underhill 1974, Inskip 1982). Any one spawning group can release gametes over a large area of spawning habitat (Koshinsky 1979). Franklin and Smith (1963) found the number of eggs produced to be highly dependent on female body size, described by the equation \( y = 4401.4x - 66245 \), with \( y \) equal to the number of eggs produced, and \( x \) as the total length of the fish in inches. Females weighing 0.75 lbs may produce from 9,000 to 10,000 eggs, while a female weighing 10 lbs may produce 100,000 eggs (Lagler 1956).

Environmental optima and tolerances

Northern pike are a cool water species, but have a wide range of environmental tolerances including water temperature, dissolved oxygen concentration, and water clarity, which, in part, can be attributed to their success as an invasive species (Casselman 1978, Steinberg 1992, Casselman and Lewis 1996). These optima and tolerances, however, vary among life-cycle stages (Inskip 1982). *E. lucius* embryos are tolerant of temperatures up to 19°C (Siefert *et al.* 1973), with maximum hatching success occurring at temperatures from 9-15°C and severe mortality at temperatures near 5°C (Hassler 1970). Dissolved oxygen
concentrations of 4.5 mg/L is optimal for embryo development, while concentrations of 3.2 mg/L or less result in high embryo mortality (Siefert et al. 1973). Embryos are particularly sensitive to high rates of siltation ($\geq$1 mm/day) (Hassler 1970), and exposure to hydrogen sulfide of concentrations greater than 0.014-0.018 ppm for 96 hours decreases hatching success (Adelman and Smith 1970a). Fry survival and growth is greatest at temperatures from 18.0-20.8°C, with poor survival at temperatures lower than 5.8°C and higher than 25.6°C (Lillelund 1966, Hokanson et al. 1973). Hydrogen sulfide concentrations greater than 0.004-0.006 ppm for 96 hours significantly decreased survival of yolk sac fry (Adelman and Smith 1970a).

Juvenile *E. lucius* reach maximum growth rates at temperatures ranging from 19-21°C, with significantly decreased survival at temperatures lower than 3°C and above 28°C (Casselman 1978). Growth rates were hindered at dissolved oxygen concentrations below 7 ppm, and very low juvenile survival occurred at concentrations below 3 ppm (Adelman and Smith 1970b). Feeding ceased at less than 2 ppm and no fish at dissolved oxygen concentrations of 1 ppm survived more than 20 hours in a study by Petit (1973).

Adults have the greatest environmental tolerances of the life-cycle stages, with a maximum temperature tolerance of over 30°C (Ridenhour 1957). Optimum growth occurs at approximately 20-21°C, but adult *E. lucius* have shown no apparent stress at temperatures as low as 0.1°C prior to freezing in a shallow lake (Casselman 1978). Despite these wide temperature tolerances, sudden drops in temperature can be lethal (Ash et al. 1974, Inskip 1982). A significant decrease in feeding has been observed in adults exposed to dissolved oxygen concentrations around 2-3 mg/L, and feeding has been shown to stop altogether at concentrations less than 2 mg/L (Adelman and Smith 1970b, Casselman and Lewis 1996). *E. lucius* can inhabit areas with pHs ranging from 6.1-8.6 (Margenau et al. 1998), and can tolerate some salinity, having been found frequently in the Baltic Sea (Crossman 1979).

**Biotic associations**

Biotic associations of *E. lucius* vary across the native and introduced range of the species, although there are numerous pathogens and parasites that can be associated with this species. One notable ectocommensal organism associated with *E. lucius* is the ciliate *Capriniana piscium*, also known as *Trichophyra piscium*. *C. piscium* attaches to the lamellar epithelia of the gill surface of *E. lucius* using microfibrils that connect to the host cell membrane (Lom 1971, Hofer et al. 2005; Figure 2). It was previously thought that high densities of these organisms could cause tissue damage in the host, however, there is no evidence of *C. piscium* feeding on the host cells (Lom and Dykova 1992). Instead, this commensal uses its tentacles to feed on ciliates that are in the water...
that passes through the fish gill lamellae (Lom 1971, Dovgal 2002, Hofer et al. 2005).

Current geographic distribution

Distribution in the United States and the PNW

In the United States, the native range of *Esox lucius* includes the Great Lakes and Mississippi River basins as well as Alaska, Pennsylvania, Missouri and Nebraska (Page and Burr 1991), and the South Saskatchewan River Drainage in Montana (Holton and Johnson 1996). However, *E. lucius* has been reported to have non-native populations in 41 states, including Washington, Oregon and Idaho (Figures 3 and 4).

In the Pacific Northwest, *E. lucius* has an established population in Coeur d'Alene Lake, Idaho, and has been reported to have established populations in the Spokane River in both Idaho and Washington, as well as Lake Pend Oreille, Idaho, and the Pend Oreille River in Washington and Idaho. There have also been general reports of the presence of established *E. lucius* populations in the Columbia River in Oregon as well as Washington (Fuller 2011) (Figure 4).

History of invasiveness

*Eox lucius* has a long history of introduction and subsequent invasions, both in the United States and elsewhere. This species is historically absent from Mediterranean France,
central Italy, southern and western Greece, and northern Scotland, but has been widely translocated throughout Europe (Kottelat and Freyhof 2007), introduced to Spain, Portugal, and Ireland (Welcomme 1988), among other locations. *E. lucius* has also been introduced to Algeria, Ethiopia, Madagascar, Morocco, Tunisia, and Uganda (Welcomme 1988, Lever 1996).

As an important game fish, the introduction history of *E. lucius* outside of its native range in the United States dates back to the 1800’s. The first recorded introduction of *Esox lucius* in the United States outside of its native range was in the 1840’s when the United States Fish Commission intentionally introduced the fish into the Hudson River Basin, where it subsequently spread to the lower Hudson River by 1976 (Mills et al. 1997). Widespread stocking of *E. lucius* in the Chesapeake Basin began in the 1960’s in Pennsylvania, followed by stocking in Maryland and Virginia (Denoncourt et al. 1975). In 1992, 4000 *E. lucius* fingerlings were released in the District of Columbia, although the survival of these fishes is unknown (Christmas et al. 2000). In Colorado, *E. lucius* was introduced to the Elk-head Reservoir of the Yampa River drainage in 1977, where they subsequently invaded the Green River basin of Colorado and Utah in 1981 (Wick et al. 1985), with similar introduction histories for other states with established *E. lucius* populations.

Figure 4: Native and invaded range of *E. lucius* in the Pacific Northwest with general ranges as well as point occurrences of populations (Adapted from the US Geological Survey 2011).
*E. lucius* was first introduced to the Pacific Northwest in the early 1950’s (Brown 1971) and now occurs throughout the Columbia River basin. It was illegally stocked into Coeur d’Alene Lake, Idaho, in the early 1970’s (Rich 1993), where it then spread into several other lowland lakes in northern Idaho (McMahon and Bennett 1996). Although *E. lucius* is native to Montana in the Saskatchewan River drainage, it has now spread throughout the state (DosSantos 1991), and has also spread to Idaho, Washington and Oregon.

**Invasion process**

*Pathways, vectors and routes of introduction*

The primary introduction pathway of *Esox lucius* is the intentional stocking of the fish for recreational purposes (Fuller 2011). As an important sport fish, *E. lucius* has been intentionally introduced across the country initially by the United States Fish Commission, and later by various state agencies, to stimulate fishing opportunities in various parts of the country (Jenkins and Burkhead 1993; Scott and Crossman 1973). Intentional introductions still occur due to public pressures for fishing opportunities, despite the risks associated with introductions (McMahon and Bennett 1996). Illegal stocking, or bait-bucket transfer, also frequently occurs, in which *E. lucius* are intentionally introduced to an ecosystem without authorization. This is typically done to promote fishing opportunities in the recipient ecosystem for those stocking the water body, but this unregulated introduction of *E. lucius* can play a large role in facilitating the spread of this species (McMahon and Bennett 1996).

In the Pacific Northwest, one of the initial introductions of *E. lucius* was via illegal stocking with Coeur d’Alene Lake, Idaho (Rich 1993), resulting in the subsequent spread of this species across northern Idaho. *E. lucius* populations in Washington are a result of illegal stocking in the Flathead, Bitterroot and Clark Fork River systems in Montana. These fish then migrated into Lake Pend Orielle, through Idaho by way of the Pend Orielle River, into Washington (Washington Department of Fish and Wildlife). In the past few years, these fish have spread from Boundary Reservoir into the Columbia River, and can now be found in Oregon as well, most likely though downstream migration in the Columbia River (McMahon and Bennett 1996).

*Factors influencing establishment and spread*

The establishment and spread of a species is determined by the environmental tolerances of that species, as well as certain life-history characteristics. *E. lucius* can withstand a wide range of environmental conditions (Casselman 1978, Steinberg 1992, Casselman and Lewis 1996), increasing the likelihood of establishment and spread of this species due to the fact that there is a large amount of habitat with tolerable environmental conditions available. *E. lucius* is also a relatively fecund species (Casselman and
Lewis 1996), which may allow for rapid establishment of populations and subsequent spread to new areas. The main factor that may restrict the ability of *E. lucius* to establish and spread, however, is the availability of shallow habitat with submerged vegetation (DosSantos 1991) vital in spawning as well as adult foraging, as well as the presence of suitable fluctuation of water levels during the spawning period (see life-cycle section) (Inskip 1982). The nature of these specialized habitat requirements therefore serve to limit the distribution and likelihood of spread (Jones 1990). Because these fish are highly predatory, an abundant prey base in the recipient community is also necessary to support *E. lucius* populations (McMahon and Bennett 1996), which may further constrain the amount of suitable habitat available for colonization.

**Potential ecological and/or economic impacts**

There are many potential ecological and economic impacts associated with the introduction of *E. lucius* outside of its native range. As a keystone piscivore, this fish can shape the composition, abundance and distribution of fish communities (Craig 2008), which has important implications when considering the native fish communities, as well as sport fisheries. In places where *E. lucius* is overpopulated, there is a resultant overfeeding on their prey base, which impedes the growth of these fish. Stunted growth, however, does not result in lower reproduction, so overabundant *E. lucius* populations can not only severely decrease prey fish abundances (He and Kitchell 1990), but also create undesirable fisheries due to their small size. If *E. lucius* populations were left unchecked, they could cause a loss of revenue from sport fisheries as well as have drastic impacts on native fish populations (Washington Department of Fish and Wildlife). The effects that *E. lucius* can have on native fishes have very important implications, especially when considering the native fishes of the Pacific Northwest. One of the main concerns associated with the spread of *E. lucius* is the impact this species can have on local salmon populations (McMahon and Bennett 1996). *E. lucius* have been shown to have drastic negative impacts on salmon populations as they feed on salmon smolts migrating to sea (Larson 1985, Petrovozvanskiy *et al.* 1988) and these fish have been associated with the extinction of local salmonid populations (Bystrom *et al.* 2007, Spens 2007, Spens and Ball 2008), making their invasion a serious threat.

While the introduction of *E. lucius* threatens to cause serious declines in a popular Pacific Northwest sport fish, *E. lucius* in itself is also an important sport fish, and there are strong economic benefits associated with the introduction of this species. Stocking of these fish can generate popular sport fisheries, which can create important revenue that enhances local economies (McMahon and Bennett 1996). However, this economic benefit can to lead to an increase in the frequency of illegal stocking
(Vashro 1990, 1995), further contributing to the continued spread of *E. lucius* and the harmful effects that can follow.

**Management strategies and control methods**

There are several different management strategies and control methods for *Esox lucius* populations, the most effective of which, however, is prevention. Once established, these fish can spread to neighboring habitats, drastically affecting the recipient biotic communities (He and Kitchell 1990, Craig 2008), making a preemptive response the best approach. One of the main prevention strategies is education, allowing for an early-warning system for new introductions in which a quick response can be enacted, as well as increasing awareness of the impacts of *E. lucius*, hopefully deterring the intentional introduction of the species.

However, in the cases where introduction has already occurred, primary strategies for the control of *E. lucius* include the suppression of *E. lucius* populations, the prevention of spread to other waterways, and removal of as many organisms as possible using a variety of methods. Prevention of spread to other waterways is particularly important in attempting to control *E. lucius* populations, because by limiting their access to habitat it constrains their ability to spread and establish subsequent populations. Electrofishing, trapping and the use of rotenone, a fish toxicant, are common strategies for fish population suppression and removal, although they tend to be costly and/or labor intensive, with tradeoffs associated with each strategy (CDF&G et al. 2006).

An important management strategy in preventing the spread of *E. lucius* is regulation of illegal introductions. Many states have laws that prevent the transport of live fish from a waterbody (e.g., Idaho, Oregon, and western Montana), but there is strong opposition from the public and it is difficult to closely manage the actions of individuals stocking fish illegally (McMahon and Bennett 1996). In Montana, the legislature stiffened penalties associated with the illegal stocking of fish, such as fines, suspension of fishing privileges, and liability for cost of restoring a fishery, and they have even offered rewards for reporting such activity (McMahon and Bennett 1996). Following the actions of the Montana legislature in creating public incentive seems to be a good place to start in terms of finding better ways to raise awareness and prevent the introduction of invasive species.

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Expert contact information in PNW

David H. Bennett
Fish and Wildlife Resources Department
University of Idaho, Moscow, ID 83844-1136
dbennett@uidaho.edu

Thomas E. McMahon
Biology Department, Fish and Wildlife Program
Montana State University, Bozeman, MT 59717-0346
ubitm@msu.oscs.montana.edu

Deane Osterman
Executive Director for Natural Resources
Kalispel Tribe
Kalispel Tribal Headquarters
P.O. Box 39
Usk, WA 99180
Phone: (509) 445-1147
Fax: (509) 445-1705

Current research and management efforts

Currently, there are numerous ongoing efforts to control the spread of *Esox lucius*, with a focus on eradicating populations that have been introduced illegally. In Montana, *E. lucius* removal programs have been implemented in the Milltown Dam Reservoir to help restore native cutthroat and bull trout. The dam impedes
salmonid migration causing them to concentrate in the reservoirs, providing easy prey for the *E. lucius* that reside there (Dickson 2003). The Montana Department of Fish, Wildlife, and Parks have temporarily lowered the later levels of the reservoir each year to kill yearling *E. lucius* that occupy the back channels, resulting in reduced fish populations, although the process is labor intensive. Montana has also recruited angler organizations to help control *E. lucius* populations, as well as prevent illegal introductions (McMahon and Bennett 1996).

The California Department of Fish and Game (CDF&G) has been treating a lake with an *E. lucius* population with rotenone, a common fish toxicant, in an attempt to eradicate the fish. The first time this was done, *E. lucius* were found two years later, so another eradication attempt is planning to be undertaken (CDF&G et al. 2006). Experimental control measures such as the use of net barriers, electrofishing, and encircling nets are also being used to control *E. lucius* populations, as well as the blockage of spawning areas, reducing food availability, increasing public awareness and implementing a comprehensive fish monitoring program.

In Washington, management efforts are being directed towards minimizing the impacts of *E. lucius* on native fish species and reducing *E. lucius* abundances in the Box Canyon Reservoir. The Washington Department of Fish and Wildlife (WDFW) is working with the Kalispel Tribe Natural Resources Department (KNRD) to devise an appropriate management strategy for the Pend Orielle River. Surveys are being conducted to determine the relative abundances of *E. lucius*, the structure of the overall fish community, and the timing of *E. lucius* spawning activities. The WDFW is attempting to learn more about the impacts of *E. lucius* on native salmonid populations, using events that occurred in south-central Alaskan watersheds as a model to attempt to prevent similar damage to Washington salmonid populations, and has proposed to remove *E. lucius*'s classification as a game fish, causing it to be listed solely as a prohibited species.