International review of impacts of pike introductions and colonisations on native fish communities

Pike stock management policies vary widely depending on the status of pike (native, invasive, locally non-native) in the managed water body, the angling preference on the water body, and the perceived or observed impact of the pike population on prey species and on the ecology of the water body. Where prey species abundance appears to have been lowered or species survival appears threatened by pike invasion, aggressive pike stock control measures including culls and eradications have been adopted (Schwörer et al., 2012). However, management policies which seek to enhance pike stock or pike stock structure have also been proposed and adopted in waters where pike are native and pike angling is popular (Arlinghaus et al., 2010).

Peer-reviewed pike control (i.e. management for the enhancement of prey fish communities) studies are outnumbered in the scientific literature by peer-reviewed studies of ecological impacts of pike introductions or colonisations (outside their native range) on prey-fish communities. Therefore, although this overview was initially intended to examine pike management literature, what follows is a review of pike invasion impacts on local ecology and resident fish species. Given that the impact of pike on prey species is a contested issue this review should, at the very least, provide some context to claims made by pro- and anti-pike management groups. However, there may be some papers which have been missed and further work may be necessary.

Pike-salmonid interactions are of particular relevance to the question of pike control in designated wild brown trout fisheries in Ireland and a substantial body of research exists for such population interactions based on field studies in Alaska, Sweden, and the UK. I focus on pike-salmonid interaction studies where possible but several relevant studies, particularly in North America, on pike interaction with other prey species have been reported and are included here. A key consideration when reading these papers is the influence of environment and habitat on the effects of pike introductions or invasions on existing prey species. The last section of the report attempts to assess without bias the relevance of the international studies to an Irish context.

Alaska and North America

Pike in salmonid waters

Investigations and reports into impacts of pike invasions or introductions in Southcentral Alaska (and any management policies adopted or recommended) highlight the problems faced by managers of salmonid waters where locally non-native pike have been introduced. In a "grey literature" report on a pike diet and movement study for the Alaska Department of Game and Fisheries, Rutz (1999) hypothesised that pike were responsible for declines in salmonid in the Susitna River Basin. This hypothesis was based on the conclusion from statistical analysis of the dietary study findings that pike prefer salmonid prey in the Susitna waters. In the absence of the peer-review process it is difficult to assess the validity of this hypothesis. However, this report has been cited in other scientific papers from Alaskan ecologists.

Recently, Sepulveda et al. (2013) presented findings from a dietary study of pike in two Southcentral Alaskan rivers (Deshka river and Alexander Creek) with very different hydromorphologies. The main channel of the Deshka river is dominated by deep, fast-flowing waters whereas the Alexander Creek has a mainstem with slow-moving waters on low gradients surrounded by densely vegetated side-channel sloughs. In the Deshka river, abundance of multiple salmonid species remains sustainable despite pike introduction in the 1970s. On the other hand, salmonid abundance in the Alexander Creek system has declined significantly since the late 1990s. Suitable pike habitat (shallow, weeded areas with slow moving waters) is plentiful in Alexander Creek whereas it is scarce in the Deshka system. This illustrates how salmonid population response to pike introduction depends on local environment and habitat.

Sepulveda et al. (2013) sought to understand the trophic adaptability (ability to switch food sources) of pike after a decline in its preferred food source (salmonids) through this dietary study. Significant findings include that:

- pike consumption of salmonids was high relative to salmonid numbers in the low-salmonid-abundance ecosystem (Alexander Creek);
- pike adapt to declines in preferred food sources by switching consumption to other fish species and taxa/macroinvertebrates;
- pike impacts on prey species may be limited by habitat.

Based on the Alexander Creek surveys and data Sepulveda et al. concluded that pike predation pressures can switch to other species after declines in salmonids and thus can drive multiple species to low abundance.

Impact of pike introductions on other prey fish species

- Evidence of pike trophic adaptability is supported by the findings of Haught and von Hippel (2011) who observed that pike supplemented their piscivorous diet with macroinvertebrates as native stickleback abundance decreased following a dietary study in over 30 lakes in the Cook Inlet Basin, Alaska. Predation pressures continued even at low preferred-prey (stickleback in this instance) abundance because pike could thrive by supplementing their diet with macroinvertebrates. Pike may have a continued detrimental effect on prey-fish abundance.
- Patankar et al. (2006) documented the apparent extirpation (local extinction) of a native, weakly armoured, three-spined stickleback in Prator Lake – a small 40 hectare (ha) boreal lake in Alaska – following a pike introduction. The authors noted that stocking of salmonids may also have contributed to the apparent extinction of the stickleback; however, stickleback extinction was observed to coincide with the pike introduction whereas salmonid stocking had occurred over a longer period.
- Long-term effects of a pike introduction experiment in three small Boreal Shield lakes in the Experimental Lake Area (ELA), north-western Ontario, Canada were assessed by Nicholson et al. (2015). Pike introduction occurred in the late 1980s and early 1990s and surveying and monitoring continued for several years until the late 1990s

or 2000. Prey fish extirpation was observed for one lake in the original study, a small yellow perch population persisted in another lake (where pike removals were implemented until 2000), and in the third lake prey fish status was unknown. Upon return to the two lakes with possible prey fish stocks in summer 2012, Nicholson et al. (2015) observed complete extirpation of prey fish populations in both cases.

- He and Kitchell (1990) analysed changes in naive prey fish community populations following the experimental introduction of pike in a Winsconsin research lake. The magnitudes of prey-fish abundance variations were found to be strongly species-dependent; species-selective predation was a significant factor in fish community changes.
- DeBates et al. (2003) examined fish community structure (bluegill, yellow perch, largemouth bass) in a Nebraska lake before (1998) and after (2002) the establishment of a high density pike population. Abundances of bluegill and yellow perch decreased and size-structures were observed to have changed significantly over the relatively short period of the establishment of the pike population.

Both Nicholson et al. (2015) and Haught and von Hippel (2011) concluded that prey fish populations in lakes without endemic (native) piscivores were more likely to be extirpated owing to poor or slow adaptability to novel predation pressures.

General conclusions from US studies

Influence of environment and habitat on pike impact

- Haught and von Hippel (2011) concluded that habitat and environmental factors can mediate the impact of pike on prey species. For example, large lakes with pelagic waters offer prey refugia (pike feed in littoral near-shore zones); lakes with limited suitable pike spawning area impose restrictions on pike recruitment.
- Sepulveda et al. (2013) also considered environmental impacts on pike-prey interactions: pike abundance and impacts on prey fish were observed to be larger in the Alexander Creek where pike habitat was not limiting than in the Deshka river where a dearth of suitable habitat restricted pike recruitment.

Pike control measures

- Sepulveda et al. (2013) concluded that pike control is necessary where suitable rearing habitat (shallow, slow-moving waters with extensive vegetation coverage) is not limiting in order to improve prey-fish (e.g. salmonid) abundance.
- Removal of young pike (< 400 mm) in particular was recommended by Sepulveda, based on dietary study, to ease predation pressure on salmonids.
- DeBates et al. (2003) concluded after surveying a Nebraska lake (25 ha) that “If the management objective for similar lakes is to provide quality fisheries for bluegill and yellow perch, northern pike should be excluded from the fish community”

Sweden and Scandinavia

Impact of pike introductions on salmonids

Byström et al. (2007) investigated effects of pike invasion on fish community structure and lower trophic levels in a small (5.2 ha) subarctic lake in northern Sweden. Prior to the invasion of pike, the top predator was Arctic charr as is common in many high latitude and Alpine lakes. In such cold water environments, Arctic charr maintain an evolutionary advantage of optimal growth and activity/performance at low temperatures (15C and 11C, respectively) over species such as pike (21C for optimal growth). Furthermore, winter survival rates mean Arctic charr recruitment is likely to be significantly more successful than that for pike in high latitude lakes. However, pike is a more efficient piscivore (body size, gape size, growth rate etc.) than Arctic charr at their respective species-specific temperature optima. Therefore, increases in temperatures in a given high latitude freshwater ecosystems should lead to improvements in pike performance and thus increase the likelihood of pike establishment at the expense of Arctic charr. In their study, Byström et al. found that significant changes in existing fish community occurred during the study period 2002– 2005 owing to the pike invasion: pike replaced Arctic charr as the top predator and the abundance of prey species nine-spined stickleback decreased by an order of magnitude. It was hypothesised that a combination of competition for resources (stickleback, macroinvertebrates) and predation from pike led to the exclusion/extirpation of charr.

Hesthagen et al. (2014) reports a study on the impact of introduced pike on a brown trout population in a feeder stream to a small Norwegian lake (Lake Skeltjønna, surface area 3.65 ha). A dense population of small-sized brown trout were supported in the lake; however the population was virtually extinct by 1991, four to five years after the first observation of pike. The feeder stream under investigation (Skeltjønna Beck) is the only spawning and nursery stream for brown trout in the system. Surveys of brown trout numbers in Skeltjønna Beck were carried out from 1987–1995 and it was found that abundance and size-structure of brown trout changed considerably in this period. All age groups suffered declines in abundance with age 2+ brown trout suffering the largest reduction. In the absence of significant environmental changes (eutrophication, warming waters, etc.) over the period in question, these declines were attributed to the introduction and establishment of a pike population in the lake and associated feeder streams.

Influence of environment and habitat on pike impact

Hesthagen et al. (2014) noted that Lake Skeltjønna is a shallow and small lake so that predation avoidance was not possible as a survival strategy for the brown trout. However, the feeder stream did not provide suitable habitat for large pike and so brown trout who did not migrate to the lake could survive despite predation pressure from smaller pike. These allopatric brown trout reproduce and support the stream population.

Spens and Ball (2008) conducted an empirical field study in which pike-salmonid coexistence was examined using a set of hierarchical filters applied to over a thousand lakes in northern boreal region of Sweden.

Hein et al. (2014) investigate the "context dependency" of species interactions and how they influence coexistence for pike and brown trout in Swedish lakes. Context dependency refers to changes in species interactions (both in strength and nature) owing to variations in environmental factors. For example, as discussed by Byström et al. (2007), pike and brown trout have different thermal performance curves and pike propensity to catch brown trout decreases in low (<10 C) water temperatures [requires reference] . A model predicting coexistence was developed based on pike and brown trout occurrence for Swedish lakes based, initially, on six predictor variables: lake and catchment area, maximum depth, mean annual air temperatures, number of species present, and lake elevation. The most significant predictors of coexistence were temperature and area (and a combination of these factors) for the subset of lakes considered. Crucially, it was concluded that "coexistence is most threatened in small lakes (less than 1 km^2)". Other mechanisms in large lakes allowing coexistence include the presence of deep, cold pelagic zones which can provide a refuge for brown trout from pike predation. Furthermore, availability of alternate prey species may ease predation pressure on brown trout although effects of competition between brown trout and other species were considered to be uncertain.

Relevance to Ireland's designated wild brown trout fisheries

International studies on pike introductions and impacts on wild brown trout populations serve a useful purpose of highlighting possible significant changes in fish community abundance owing to introduction of pike. However, many of the case studies of native fish population extirpation discussed here apply to northern boreal lakes. Most northern boreal lakes (created during the deglaciation period at the end of the last ice age) are geographically distinct from the Irish wild brown trout fisheries, namely they have much smaller surface areas and are typically quite shallow. For example, in Spens and Ball's study the average lake surface area is 41 ha. Less than 10 lakes from a total of 1000 were larger than 1000 ha. In contrast, of the 14 designated wild brown trout fisheries only Lough Inchiquin (108 ha) and Loughrea (260 ha) have surface areas less than 1000 ha.[1]

Hein et al. (2014) included lake area as one of the six key factors in determining pike-trout population interactions. These predictor variables should broadly apply to Irish lakes also. Therefore, number of species present, lake depth, and lake area are likely to be key determinants for interactions between pike and brown trout for the designated wild brown trout lakes in Ireland. Only two of the designated wild brown trout fisheries are less than 1 km^2 or 100 ha) – considered small by Hein et al. (2014) – and so the other twelve lakes can be considered medium-sized or large.

Availability of suitable pike habitat will also determine carrying capacity for pike in lakes and rivers (see Sepulveda et al. (2013)). This has already been acknowledged in an Irish context by O'Grady and Delanty (2008) (Central Fisheries Board report) who noted that the withdrawal of management operations in Loughs Derravarragh, Ennell, and Owel did not result in significant changes in pike abundance or recoveries in wild brown trout abundance (Lough Ennell) following stream enhancement programmes. O'Grady and Delanty (2008) also remarked that Lough Inchiquin is very deep lake with only limited areas of dense lake vegetation so that pike control is not necessary owing to the combination of large a pelagic refuge and limited pike habitat.

---

[1] For this reason the paper by Spens and Ball (2008) is only briefly considered.

Finally, eutrophication of waters and establishment of (other) invasive species such as roach (now abundant in many designated wild brown trout fisheries) will also significantly alter the dynamic of pike and trout interactions so that simple extrapolations from case studies based in very different environmental and geographical conditions are likely to be misleading.

Important questions remain to be answered with regard how pike-trout interactions depend on the ecology, geography and habitat (i.e. the context) of designated Irish brown trout fisheries including:

- Can satisfactory levels of trout abundance for anglers be maintained in large lakes where habitat refuges from predation exist?
- Will competition from coarse fish mean that trout benefit from pike presence or will pike predation pressures have negative effects on trout abundance?
- Does water quality play a significant role in determining trout success relative to pike?
- How do the quality of feeder streams and the presence of pike in such streams affect trout abundance? Many reports from anglers and fisheries' officer concerning large-scale predation by pike on juvenile trout exist: do these anecdotal observations translate to a whole-lake population dynamic?

References

Arlinghaus, R., Matsumura, S., Dieckmann, U., (2010). The conservation and fishery benefits of protecting large pike (Esox lucius L.) by harvest regulations in recreational fishing. Biol. Conserv. 143, 1444–1459.

Byström, P., Karlsson, J., Nilsson, P., Van Kooten, T., Ask, J., Olofsson, F., (2007). Substitution of top predators: Effects of pike invasion in a subarctic lake. Freshw. Biol. 52, 1271–1280.

DeBates, T.J., Paukert, C.P., Willis, D.W., (2003). Fish community responses to the establishment of a Piscivore, Northern Pike (Esox lucius), in a Nebraska Sandhill Lake. J. Freshw. Ecol. 18, 353–359.

Haught, S., von Hippel, F.A., (2011). Invasive pike establishment in Cook Inlet Basin lakes, Alaska: Diet, native fish abundance and lake environment. Biol. Invasions 13, 2103–2114.

He, X., Kitchell, J.F., (1990). Direct and Indirect Effects of Predation on a Fish Community: A Whole-Lake Experiment. Trans. Am. Fish. Soc. 119, 825–835.

Hein, C.L., Öhlund, G., Englund, G., (2014). Fish introductions reveal the temperature dependence of species interactions. Proc. Biol. Sci. 281, 20132641.

Hesthagen, T., Sandlund, O.T., Finstad, A.G., Johnsen, B.O., (2014). The impact of introduced pike (Esox lucius L.) on allopatric brown trout (Salmo trutta L.) in a small stream. Hydrobiologia 744, 223–233.

Nicholson, M.E., Rennie, M.D., Mills, K.H., (2015). Apparent extirpation of prey fish communities following the introduction of Northern Pike (Esox lucius). Can. Field-Naturalist 129, 165–173.

O'Grady, M. (Central F.B., Delanty, K. (Central F.B., (2008). The Ecology, Biology and Management of Pike in Irish Waters With Particular Reference to Wild Brown Trout Lake Fisheries.

Patankar, R., Von Hippel, F.A., Bell, M.A., (2006). Extinction of a weakly armoured threespine stickleback (Gasterosteus aculeatus) population in Prator Lake, Alaska. Ecol. Freshw. Fish 15, 482–487.

Rutz, D.S.C.N.-F.-05, (1999). Movements, food availability and stomach contents of northern pike in selected Susitna River drainages, 1996-1997.

Schwörer, T., Federer, I.R., Ferren, H., (2012). Managing Invasive Species : How Much Do We Spend ? 2011–2012.

Sepulveda, A.J., Rutz, D.S., Ivey, S.S., Dunker, K.J., Gross, J.A., (2013). Introduced northern pike predation on salmonids in southcentral Alaska. Ecol. Freshw. Fish 22, 268–279.

Spens, J., Ball, J.P., (2008). Salmonid or nonsalmonid lakes: predicting the fate of northern boreal fish communities with hierarchical filters relating to a keystone piscivore. Can. J. Fish. Aquat. Sci. 65, 1945–1955.