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Eurasian tench (*Tinca tinca*): the next Great Lakes invader

Sunčica Avlijaš, Anthony Ricciardi, and Nicholas E. Mandrak

Abstract: A globally invasive fish, Eurasian tench (*Tinca tinca*) is spreading through the St. Lawrence River and poses an imminent invasion threat to the Great Lakes. Following its illegal release into a tributary of the St. Lawrence River in 1991, tench has spread throughout the river's main stem over the past decade, and its abundance in commercial fishing bycatch in the river has grown exponentially. The tench is a generalist benthic consumer with largely undocumented ecological impacts in North America. Reports from other invaded regions indicate that it can compete with other benthic fishes, host a diverse assemblage of parasites and pathogens, degrade water clarity in shallow lakes, limit submerged macrophyte growth, reduce gastropod populations, and promote benthic algal growth through top-down effects. Risk assessments and climate-match models indicate that the Great Lakes are vulnerable to tench invasion, and they signal the need for timely comprehensive actions, including development and implementation of monitoring and rapid-response protocols, including prevention or slowing of natural dispersal through canals.

Résumé : La tanche (*Tinca tinca*), un poisson envahissant à l'échelle planétaire, se propage dans le fleuve Saint-Laurent et présente une menace imminente d'envahissement pour les Grands Lacs. Dans la foulée de son lâcher illégal dans un affluent du Saint-Laurent en 1991, la tanche s'est répandue à la grandeur du bras principal du fleuve au cours de la dernière décennie, et son abondance dans les prises accessoires de pêches commerciales a connu une augmentation exponentielle. La tanche est un consommateur benthique généraliste dont les impacts écologiques en Amérique du Nord demeurent largement non documentés. Des rapports provenant d'autres régions envahies indiquent qu'elle peut faire concurrence à d'autres poissons benthiques, est l'hôte d'un assemblage varié de parasites et de pathogènes, cause la détérioration de la clarté de l'eau dans les lacs peu profonds, limite la croissance des macrophytes submergés, réduit les populations de gastéropodes et favorise la croissance d'algues benthiques par le biais d'effets descendants. Les évaluations du risque et les modèles climatiques indiquent que les Grands Lacs sont vulnérables à l'envahissement par la tanche et font ressortir la nécessité de mettre rapidement en place des mesures exhaustives, dont l'élaboration et l'application de protocoles de surveillance et d'intervention rapide incluant la prévention ou le ralentissement de la dispersion naturelle à travers les canaux. [Traduit par la Rédaction]

Introduction

The Great Lakes have been invaded by at least 188 non-native species (Ricciardi 2006; A. Ricciardi, unpublished data), including 28 fishes (Mandrak and Cudmore 2010). These introductions have affected water quality, nutrient cycling, contaminant cycling, biodiversity, and fish productivity in the basin through a broad variety of mechanisms ranging from trophic disruption to disease transmission (Mandrak and Cudmore 2015). Identification and risk assessment of future invaders would provide valuable information to guide the allocation of resources toward prevention, early detection, and rapid response to impede or slow spread (Ricciardi and Rasmussen 1998; Mandrak and Cudmore 2015). Here, we identify an imminent invasion threat to the Great Lakes: tench (*Tinca tinca*), a Eurasian freshwater fish that is undergoing a rapid population expansion in the St. Lawrence River. We report the results of a new risk assessment for the Great Lakes, review documented ecological impacts of tench in other invaded regions, and provide diagnostic characteristics that will facilitate identification of juvenile tench and thus aid monitoring efforts.

The tench: a globally invasive fish

The tench is a freshwater cyprinid native to parts of Europe and Asia. Its natural distribution has been obscured by several centuries of human-mediated spread, owing to its popularity since the Middle Ages as a comestible fish that is easily cultured and transportable (Bianco 1995; Garcia-Berthou and Moreno-Amich 2000). Recently, spatial genetic analysis has revealed at least some of the early effects of human-mediated dispersal on the current range of tench in Europe, including its introduction to the Iberian Peninsula at least as early as the 1500s (Lajbner et al. 2011; Lo Presti et al. 2012). As transportation systems improved in the 1800s, tench was introduced to increasingly distant locations for aquaculture or sport fishing, and it is now established on every continent except Antarctica (Fig. 1). Its establishment success has been highly variable; it no longer exists in many places where it was previously stocked (Fig. 2), whereas in some regions like Norway, it is the most widely distributed non-native fish, occurring in twice as many sites as the stocked brook trout (*Salvelinus fontinalis*) and ten times as many as sites as any other invader, including common carp (*Cyprinus carpio*) (Hesthagen and Sandlund 2007).

The tench has been introduced to North America multiple times. The population in California appears to be the result of a single introduction from Italy in 1922, in which the fish were initially bred in a pond and subsequently spread by farmers (Baughman 1947). All other introductions in North America are reported to have been sourced from Germany (Nico and Fuller 2011; Masson et al. 2013). The greatest propagule pressure of tench

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Fig. 1. Global distribution of tench by watershed. Data from Bianco (1998), Chefiri and Loudiki (2002), Clavero et al. (2004), Economidis et al. (2000), El Wartiti et al. (2008), Habit et al. (2015), Iriarte et al. (2005), Lehner et al. (2008), Lusk et al. (1998), Nico and Fuller (2011), Pelletier and Gagnon (2014), Persat and Keith (1997), Rask et al. (2000), Rowe (2004), SLGO (2016), and Xu et al. (2012). [Colour online.]

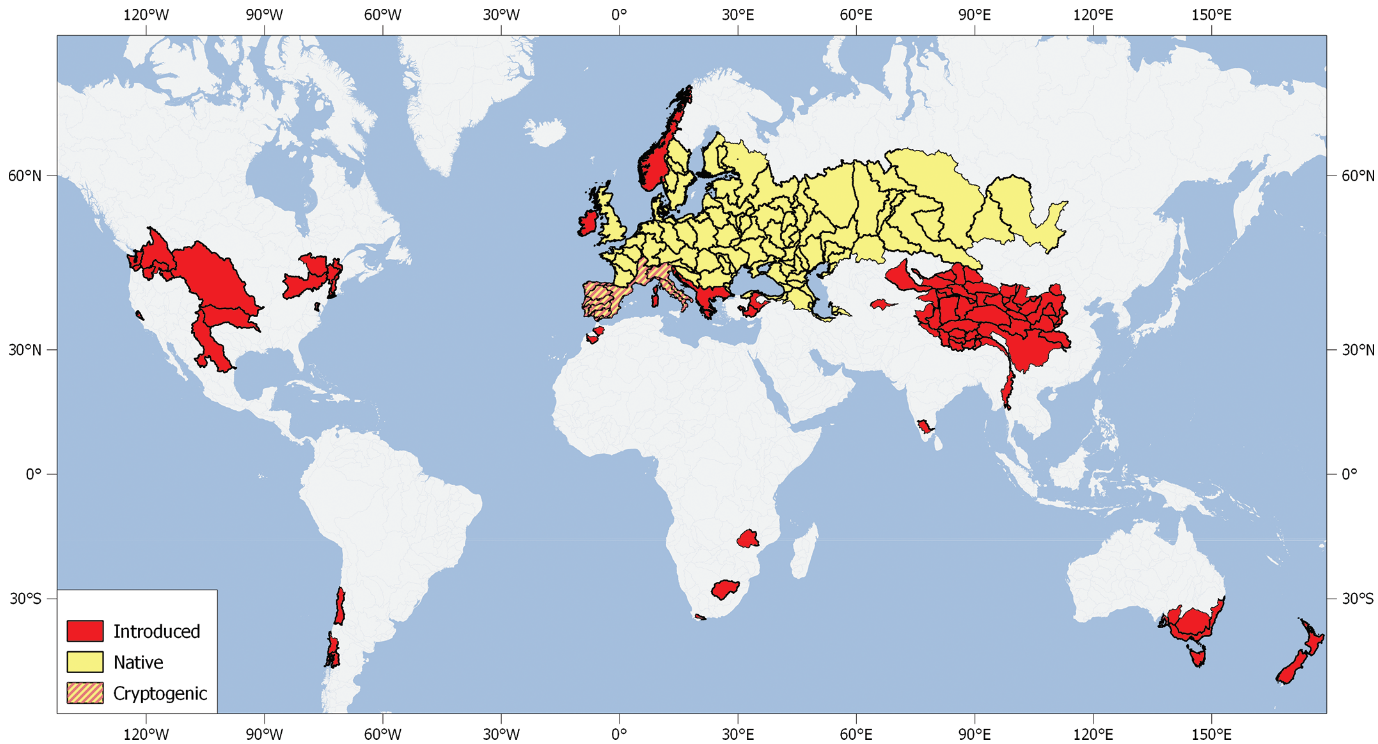
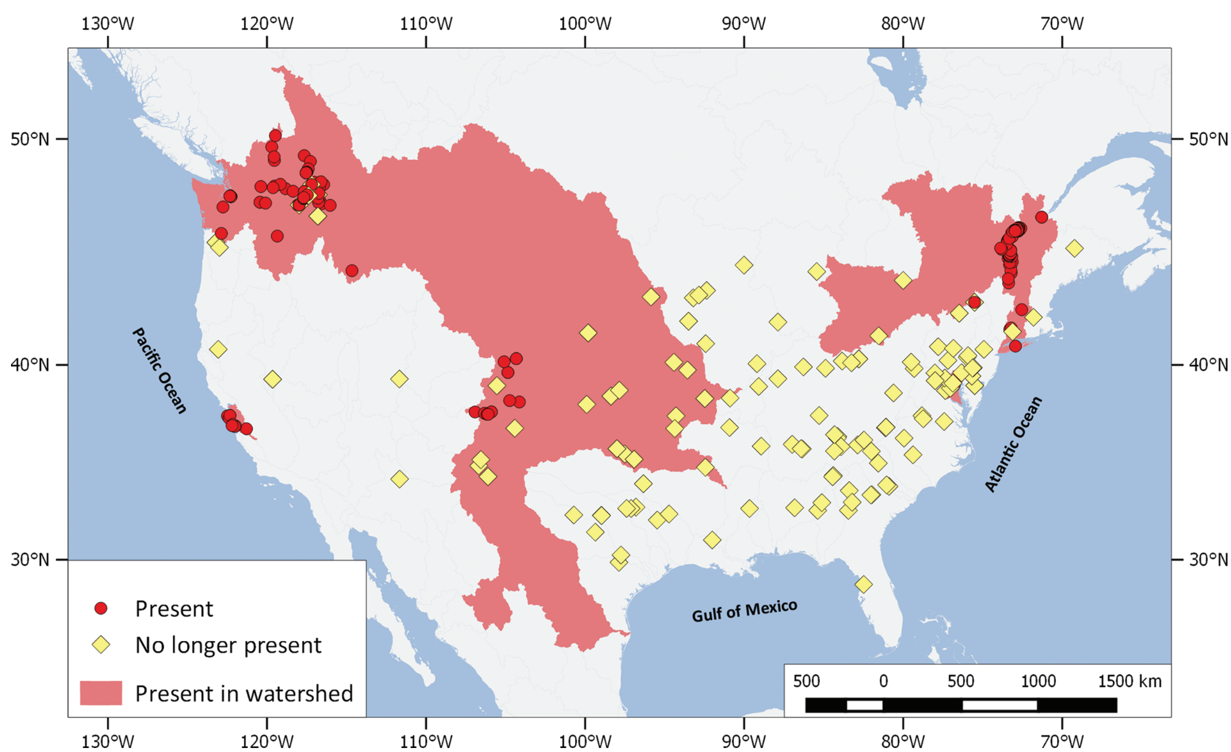
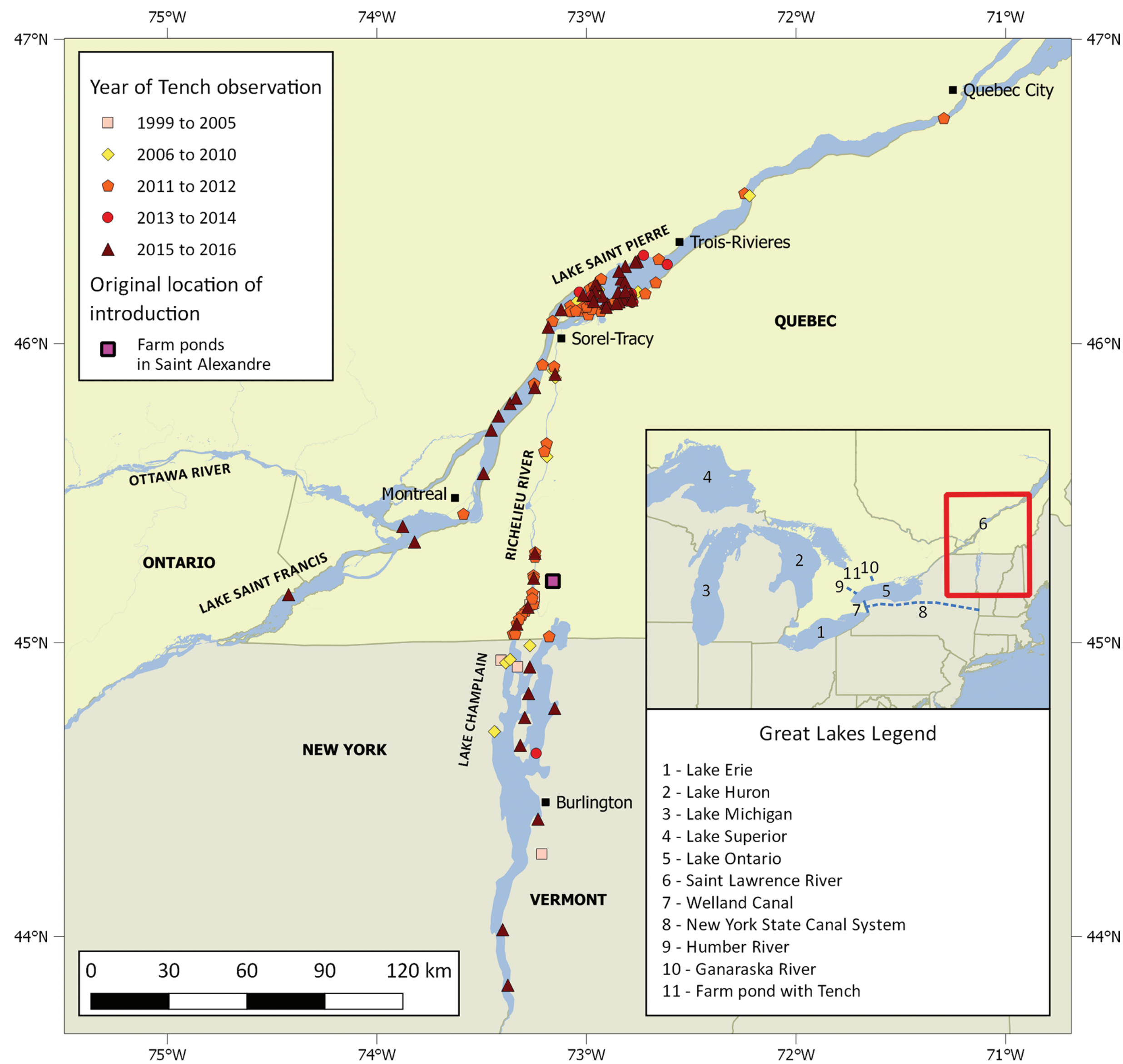


Fig. 2. Distribution of tench in North America by watershed (Lehner et al. 2008; McPhail 2017; Nico and Fuller 2011; SLGO 2016; S. Avlijaš, personal observation). [Colour online.]



occurred during the 1890s when it was stocked in watersheds throughout the contiguous USA by the Fish Commission, a government agency that bred the species in rearing ponds (Baughman 1947). In addition to conducting watershed stocking programs, the Fish Commission distributed fish to individuals who made applications to receive them for pond stocking. Today, tench populations persist at a fraction of the sites where they had initially been reported as established (Fig. 2).

Fig. 3. Spread of tench in the St. Lawrence River basin. (Guibert 2000; Masson et al. 2013; Nico and Fuller 2011; SLGO 2016; S. Avlijaš, personal observation). [Colour online.]



Recent rapid expansion in the Laurentian Great Lakes basin

The tench was illegally introduced to Quebec by a farmer who imported 30 live specimens from Germany and reared them in ponds on his property in St. Alexandre, Quebec, in the Richelieu River watershed (Fig. 3). Fish from these ponds are believed to have escaped and entered the Richelieu River in 1991 when the ponds were drained by the farmer once he concluded that there was no commercial demand for the species on the Canadian market (Dumont et al. 2002); the earliest recorded captures in the river were in 1994. A survey in the Richelieu River conducted in 2000 found mature adults and evidence of reproduction (Guibert 2000; Vachon and Dumont 2000). By 2002, tench had dispersed upstream into Lake Champlain (Marsden and Hauser 2009). In 2006, it was detected in the St. Lawrence River on both shores of Lake St. Pierre (Masson et al. 2013).

Currently, the Lake Champlain, Richelieu River, and Lake St. Pierre populations are well established and recorded at high densities locally (S. Avlijaš, personal observation, 2015 and 2016; Fig. 3). An invasive species early detection program in Lake St. Pierre conducted by the Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP) in collaboration with commercial fishermen between 2007 and 2014 found that the abundance of tench has increased exponentially in the lake (Pelletier and Gagnon 2014; see Fig. 4).

Since 2011, tench has been detected by surveys in the St. Lawrence River from Montréal to Québec City (Masson et al. 2013; SLGO 2016; S. Avlijaš, personal observation) and has recently been captured in Ontario. In the summer of 2016, the first specimen was captured in a fluvial lake (Lake St. Francis) within the Ontario waters of the river (A. Mathers, Ontario Ministry of Natural Resources and Forestry, personal communication). In 2014, an illegal stocking was reported in a farm pond in Ontario within the headwaters of the Humber River watershed of Lake Ontario; while this particular population was eradicated by the Ontario Ministry of Natural Resources and Forestry, it is alarming that tench were breeding and surviving at high densities in a pond in the Great

Fig. 4. Increase in tench captures by commercial fishermen in Lake St. Pierre participating in the early invasive species detection program between 2007 and 2014 (data from Verreault et al. 2012; Pelletier and Gagnon 2014). Effort is standardized between years, and tench catches increased exponentially after not being detected in the first 2 years.

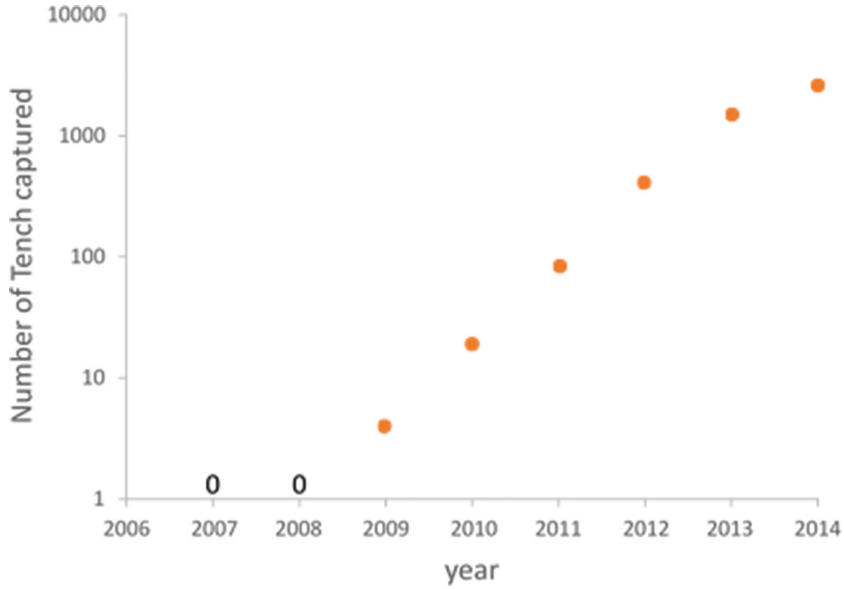


Table 1. Environmental tolerances of tench (*Tinca tinca*) reported in literature (preferred conditions are indicated in parentheses).

Variable	Lower limit	Upper limit	Reference
Spawning temperature	18–20 °C (22 °C)	25–29 °C (24 °C)	Horoszewicz 1983; Kennedy and Fitzmaurice 1970; Linhart et al. 2006; Pimpicka 1990
Temperature required to stimulate vitellogenesis	10 °C	10 °C	Pimpicka 1990
Temperature range	0 °C (20 °C)	38 °C (26 °C)	Peňáz et al. 1989
Dissolved oxygen concentration	0.4 mg·L^{-1} or 3.1%	41.2 mg·L^{-1}	Alabaster and Lloyd 1982; Beelen 2006; Downing and Merkens 1957
pH	4.5 (5.5)	10.8 (9)	Alabaster and Lloyd 1982; Anwand 1965; Duis 2001; Linhart et al. 2006
Salinity	0	12‰	Anwand 1965
Ammonia	NA	2.0 mg·L^{-1}	Alabaster and Lloyd 1982
Specific conductance	<95 μS·cm^{-1}	>824 μS·cm^{-1}	O'Maoileidigh and Bracken 1989; Tockner et al. 2003
Flow	0 m·s^{-1}	0.5 m·s^{-1} (<0.25 m·s^{-1})	van Emmerik and de Nie 2006

Lakes watershed, because the potential for a successful introduction from a farm pond to natural systems was already demonstrated in Quebec. It is highly likely that unreported tench inhabit other ponds in the area, given the lack of programs to educate the public to recognize and report this invader. Moreover, in 2015, a report on social media (including a photograph) identified tench as being captured by angling in the Ganaraska River east of Toronto. Although the report was not verified, with the rise in popularity of sports fishing apps (e.g., "Fishbrain Fishing", which reportedly has 3 million users; Fishbrain 2017), angling message boards, and social media in general, reports of potential invaders should be expected to become more frequent, and these sources of information may prove to be valuable.

Life history

Although typically found in calm, shallow (<2 m), densely vegetated waters of ponds, lakes, and large rivers, the tench has a broad environmental tolerance. Anecdotal reports suggest that it is a very hardy species that can tolerate abrasions from gill nets and survive lengthy periods out of water and can be transported between waterbodies in wet sacks (Kennedy and Fitzmaurice 1970). Its tolerance for low oxygen (Table 1) allows it to thrive in the benthic areas of lakes and eutrophic waters, including farm ponds. Tench abundance is positively related to macrophyte cover, negatively related to depth (Virbickas and Stakėnas 2016), and they show a preference for muddy substrates over concrete or sand (Rendón et al. 2003). It is active primarily at night, spending most daylight hours under the cover of macrophytes or benthic substrates (Perrow et al. 1996). In some lakes, it comprises >25% of total fish biomass (Wright and Giles 1991; Lusk et al. 1998). It has a 20-year lifespan, grows to a total length of 70 cm, and matures at 3 to 5 years (Niophitou 1993). Spawning occurs at ~18 °C in shallow, densely vegetated waters during the summer (May to August in Europe) with low flow (<0.05 m·s^{-1}) potentially multiple times in a season and involves the release of hundreds of thousands of eggs per kilogram of fish (Kennedy and Fitzmaurice 1970; Pimpicka 1991; Niophitou 1993; Mann 1996; Alaş and Solak 2004). A minimum temperature of 10 °C is required to initiate proper development of ova (Pimpicka 1990). A field study reports a significant correlation between tench year class strength and number of degree-days with water temperature warmer than 16 °C (Wright and Giles 1991); similarly, experimental evidence indicates that warming water by a few degrees results in an increase in the number of reproductive batches, a longer reproductive season, and higher cumulative fecundity of tench (Morawska 1984). Although adult tench are tolerant of acidic conditions, reproduction is impaired below a pH of 5.5, and juvenile mortalities are very high below pH 7 (Duis 2001). Tench can withstand dissolved oxygen levels as low as 0.4 mg·L^{-1} (Alabaster and Lloyd 1982) and can survive anoxic conditions as well as partial drying or freezing of lakes and ponds by burying in the mud (Baughman 1947).

The tench is a nonselective generalist predator of macroinvertebrates, including zooplankton, insects, amphipods, crayfishes, gastropods, and small bivalves (Alaş et al. 2010; González et al. 2000; Perrow et al. 1996; Michel and Oberdorff 1995; Ranta and Nuutinen 1984; Weatherley 1959), but occasionally consumes vegetation (Michel and Oberdorff 1995; Alaş et al. 2010). Although primarily a benthic feeder, it can forage throughout the water column and at the surface of calm waters. Its diet generally reflects the seasonal and spatial availability of macroinvertebrates (González et al. 2000; Giles et al. 1990; Copp and Mann 1993). It feeds largely on zooplankton (particularly large-bodied cladocerans) in the first few years of its life, whereas insects and molluscs dominate its diet in later years (Michel and Oberdorff 1995). It can forage effectively in low light conditions (Herrero et al. 2003) and over silty sediments (Petridis 1990).

History of ecological impacts

Cyprinid fishes can cause substantial ecological impacts when introduced to lakes and rivers worldwide (e.g., Tátrai et al. 1996; Britton et al. 2010; Kulhanek et al. 2011). However, the impacts of tench in North America are largely unknown and have been documented elsewhere, primarily in Europe and Australasia. Baughman (1947) provided anecdotal evidence from various parts of the United States that tench has a history as a nuisance species where it settles in high densities and, in such cases, has been considered a detriment to sport fisheries. According to Pérez et al. (2003), impacts of the aquaculture of several alien fishes including tench are said to have "created an adverse situation" for native fishes in Chile. Moyle (2002) considered tench to be a potential competitor to native cyprinids. Trophic overlap, and thus potential competition, with other cyprinids, eel, and waterfowl has been reported in Europe (Giles et al. 1990; Kennedy and Fitzmaurice 1970). Through competition, tench is suspected to have caused declines in the catch of common carp in Turkish waters (Innal and Erk'akan 2006); however, they can coexist with grass carp (*Ctenopharyngodon idella*) (Petridis 1990). Negative impacts could also arise from predation on fish eggs, which are sometimes conspicuous in tench stomachs (Wydoski and Whitney 2003).

Tench is commonly infected by a diverse assemblage of parasites and diseases (Kennedy and Fitzmaurice 1970; Ozturk 2002; Svobodova and Kolarova 2004; Ergonul and Altindağ 2005; Marcogliese et al. 2009; Alaş et al. 2010), allowing for potential transmission to other animals. For example, in a Turkish lake, 40% of 272 individuals were infected with the Holarctic cestode *Ligula intestinalis*, which can be transmitted to piscivorous waterfowl (Ergonul and Altindağ 2005). In the Richelieu River, tench carry the cestode *Valipora campylancristota*, which can reduce growth and cause mortality in cyprinids; the cestode has rarely been found in North American fishes and might have been introduced to Quebec by the tench (Marcogliese et al. 2009). Most tench in the Richelieu River have been found to also carry a parasitic copepod, *Ergasilus megaceros*, new to Canada (Marcogliese et al. 2009). In Europe and the UK, tench carry a congeneric species, *Ergasilus sieboldi*, which is considered a serious pest for aquaculture (Kennedy and Fitzmaurice 1970). Tench is also infected by diverse microbial pathogens, including spring viraemia of carp (Svobodova and Kolarova 2004).

Predation by adult tench can limit invertebrate abundance. In experimental enclosures, tench can reduce crayfish populations (Neveu 2001) and the biomass of snails and bivalves (Bronmark 1994; Beklioglu and Moss 1998). Heavy predation on snails (Beklioglu and Moss 1998) and increased inorganic nitrogen cycling caused by tench excretions (Williams et al. 2002) promote excessive epiphytic growth that interferes with the growth of submerged macrophytes such as *Elodea canadensis* (Bronmark 1994). These kinds of trophic cascades might require high densities of fish (e.g., >200 kg·ha^{-1}; Williams et al. 2002). In New Zealand, the presence of tench with other introduced fishes, rudd (*Scardinius erythrophthalmus*), goldfish (*Carassius auratus*), and common carp contributes to regime shifts in which macrophyte-dominated clearwater lakes are transformed to devegetated turbid lakes (Schallenberg and Sorrell 2009).

Tench can contribute to declines in water quality (Rowe et al. 2008) by preferentially feeding on large herbivorous zooplankton (Ranta and Nuutinen 1984; Beklioglu et al. 2003) and by disturbing sediments (de Moor and Bruton 1988). Although they do not cause sediment suspension to the same extent as common carp, they might nonetheless be detrimental to submerged macrophytes (de Moor and Bruton 1988).

Risks to the Great Lakes

Risk assessment: habitat suitability

Several assessments have been completed that are relevant to the potential risk of tench invasion in the Great Lakes. Two climate-based distribution models indicated that the Great Lakes basin has a suitable climate for tench. Using a GARP model, Stewart et al. (2006) modeled the potential tench distribution in the Great Lakes proper and concluded that large parts of Lake Erie, Lake St. Clair, the shallow areas of Lakes Huron, Michigan and Superior, as well as Lake Nipissing and Lake Simcoe in Ontario, are highly suitable for tench. Using the native range in Climatch (Australian Bureau of Rural Sciences 2016), climate match was very high (0.986) for the Great Lakes basin (N.E. Mandrak, unpublished data). Similarly, DeVaney et al. (2009) modelled the potential distribution of tench in North America using GARP and identified potential distributional areas across much of the Great Lakes region. An ecological risk screening for tench in the United States concluded that while the climate match was high, the certainty of assessment was low, and the overall risk assessment category was uncertain (USFWS 2014). However, a risk assessment conducted for this study using the Fish Invasiveness Scoring Kit (FISK; Copp et al. 2009) concluded that tench was a high risk to the Great Lakes. FISK is a risk assessment tool that scores invasion risk based on 49 questions on the biogeography, biology, and ecology of the species related to invasion stages from arrival to impact (Copp et al. 2009). The scores have been calibrated against a set of species with known establishment and impact to determine a threshold to accept (low risk) or reject (high risk) the assessed species (Copp et al. 2009). We provided responses to these questions for tench using the references used herein (see Appendix A, Table A1).

Potential pathways of introduction

Although the pathway of introduction of tench into the Richelieu River watershed is well known, there are several potential pathways for its introduction into the Great Lakes. Its occurrence in a farm pond in the extreme headwaters of the Humber River was the result of the illegal stocking conducted by a previous owner of the pond, who could not be contacted to determine the reason for the stocking. From that pond, fish collected in addition to tench included several common baitfish species (e.g., central stoneroller (*Campostoma anomalum*), fathead minnow (*Pimephales promelas*)) and northern pike (*Esox lucius*), a predator that is not native to headwater habitats (Scott and Crossman 1973); therefore, the pond was undoubtedly seeded with baitfishes. However, it is illegal to transport baitfishes into Ontario, and there is no known tench population within the province that may have been incidentally harvested with bait. Therefore, the Humber population may have resulted from baitfishes illegally transported from the nearest known population in Quebec or from illegal stocking specifically to establish tench. To identify the potential source of the various populations, genetic analyses are currently underway to determine the haplotypes of tench collected in the Humber, Lake St. Francis, St. Lawrence, and Richelieu watersheds.

The occurrence of tench in Lake St. Francis may have been the result of natural dispersal from the nearest established population in the St. Lawrence River or escape from commercial fishery holding facilities in Lake St. Francis. Lake St. Francis is an impoundment created above the Beauharnois Dam, whose lock structure allows ships to pass through the dam. As fishes have been documented passing through similar-sized locks in the Welland Canal (Kim and Mandrak 2016), it is possible that tench dispersed from known populations in the Montréal area upstream into Lake St. Francis through the locks. Alternately, the fish may have escaped from commercial fishery holding facilities in the lake. A commercial fish holding facility has been observed in the vicinity of the tench capture location, with commercial fish hauling trucks on shore nearby (N.E. Mandrak, personal observation, 2011). It is possible that fishes captured in the Quebec coarse fishery, including areas where tench is established, are held at this facility en route to Toronto live fish markets. Freshly killed tench have been observed in a Toronto market (N.E. Mandrak, personal observation, 2012).

Spread and establishment of tench into the Great Lakes basin may occur through these human-mediated pathways or through further dispersal through connecting waterways. Intentionally stocked farm ponds are stepping stones for tench spread; notable examples are in Quebec (Dumont et al. 2002), South Africa (S. Avlijaš, personal observation), California (Baughman 1947), and Norway (Hesthagen and Sandlund 2007). In Quebec, the risk of intentional spread was cited as a reason for the poisoning of farm ponds where tench populations persisted (Dumont et al. 2002). In some cases, the species is introduced because there is an interest from anglers (Hesthagen and Sandlund 2007), though in South Africa tench is often spread accidentally along with other, more desirable, angling species (S. Avlijaš, personal observation). In North America, the coarse fishing community is small, and angling for tench is negligible. Although even a few individuals interested in tench angling could cause considerable tench spread, it is equally likely for tench to be stocked accidentally in ponds within the Great Lakes watershed. Moreover, since regulations on import of live fish have become more stringent since the 1980s, the source of an introduction to the Great Lakes will most likely be the readily accessible population in the upper St. Lawrence River. Juvenile tench are easily transported in bait buckets and live wells, owing to their tolerance to poor water quality conditions.

The most direct pathway for natural spread is through the St. Lawrence River, where the population continues to expand westward. European tagging studies to estimate tench movements report that individuals travel up to 30 km when conditions at the site of initial release are not optimal, such as when tench densities are too high or there is inadequate habitat for feeding, spawning, and refuge (Brylinski et al. 1984). Perrow et al. (1996) reported that, on average, tench moved 70 $m \cdot h^{-1}$ while foraging in a small English lake. Although tench prefer very low flow conditions (below 0.25 $m \cdot s^{-1}$), the species can tolerate 0.5 $m \cdot s^{-1}$ for short time periods (Van Emmerik and de Nie 2006). Between Lake St. Francis and Lake Ontario, there is only a single set of locks at Cornwall that may slow (but not prevent) the spread of tench, as fishes tend to avoid moving through locks (Kim and Mandrak 2016). An alternate dispersal pathway into Lakes Ontario and Erie could be the New York Canal System, which connects the Hudson River, Lake Champlain (in which tench is established), Finger Lakes, Lake Ontario, and Lake Erie. The Erie Barge Canal (part of the New York Canal System) has been hypothesized to be the dispersal pathway into the Great Lakes for other invasive fishes (e.g., alewife (*Alosa pseudoharengus*), sea lamprey (*Petromyzon marinus*), and white perch (*Morone americana*); Scott and Crossman 1973). If invaded, the Great Lakes may act as a hub for dispersal beyond the basin (Rothlisberger and Lodge 2013).

Potential impacts in the Great Lakes basin

Based on our review of the literature, we predict the following impacts in areas of high habitat suitability as tench become abundant in the Great Lakes:

(*i*) increased transmission of parasites, including cestodes and copepods (e.g., *V. campylancristota*, *E. megaceros*), to other cyprinid fishes; new pathway for transmission of the cestode *Ligula intestinalis* to piscivorous birds, with negative effects on local waterfowl populations;

(*ii*) tench populations will serve as a new reservoir for the rhabdovirus that causes spring viraemia of carp and thus may contribute to increased outbreaks of the disease;

(*iii*) competitive interactions with native benthic fishes, including redhorses (*Moxostoma* spp.) and suckers (*Catosotomus* spp.), as a result of local reductions in invertebrate (especially mollusc) populations. In the upper St. Lawrence River and in some river channels in southern Ontario, tench may compete with river redhorse (*Moxostoma carinatum*), a species of concern;

(*iv*) reduced growth of submerged macrophytes, owing to sediment disturbance and trophic cascades that promote epiphytic algae;

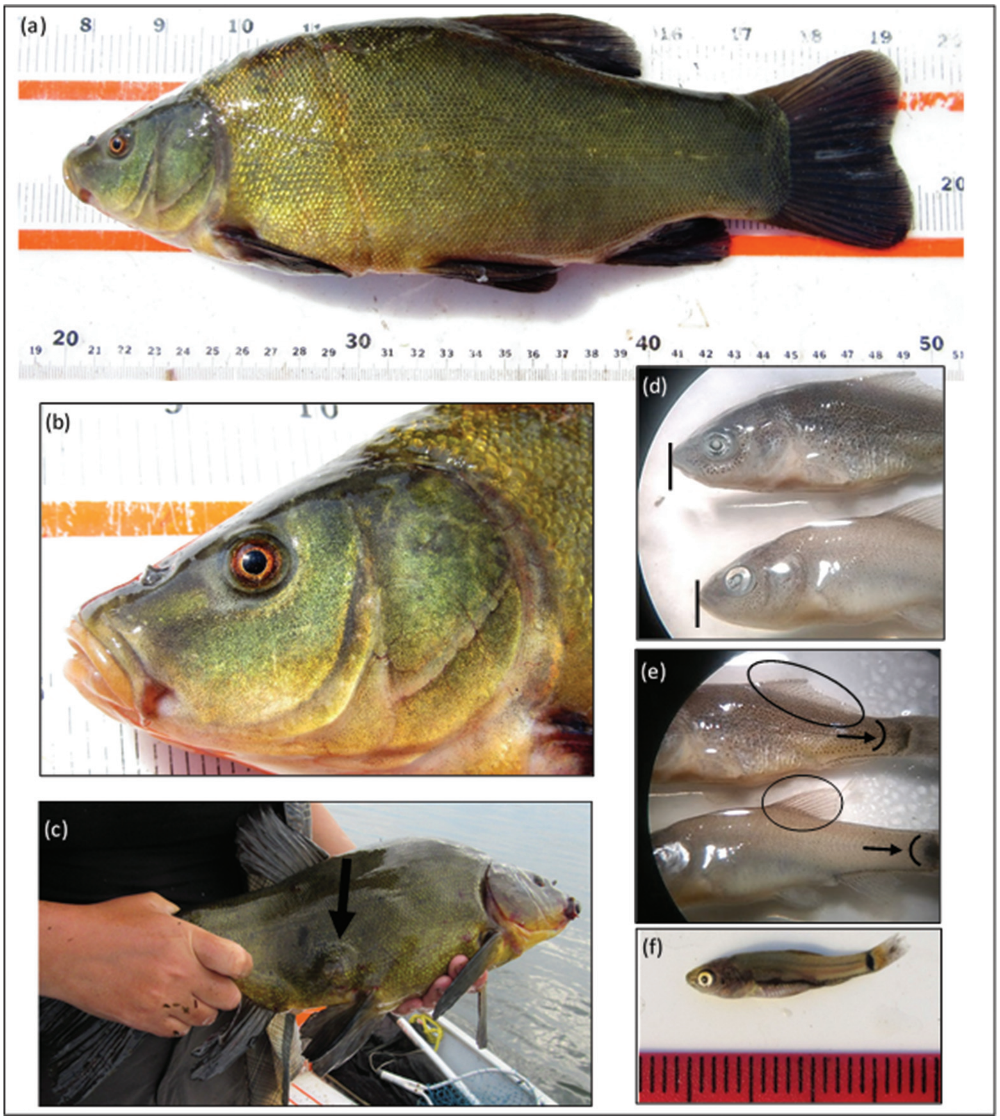
(*v*) reduced water clarity, especially in areas where tench overlap with populations of goldfish and common carp.

Early detection

Adult tench can be captured by overnight sets of fyke nets, gill nets set during the day for as few as 3 h to minimize bycatch (S. Avlijaš, personal observation, 2016), boat electrofishing at night (S. Good, Vermont Fish and Wildlife, personal communication, 2016), and backpack electrofishing in shallow areas during the day (S. Avlijaš, personal observation; Penczak and Glowacki 2008). At sites on the invasion front, where tench are at very low densities, it is often easier to detect juveniles by sampling with a beach seine. Within a site, the best areas to target are those covered in dense macrophyte beds, with low flow and fine sediments (S. Avlijaš, personal observation, 2016). Ideally, monitoring of natural dispersal should be done using multiple gears (including novel methods such as eDNA) at least once a year in suitable habitat both upstream and downstream of the location where tench are known to be established. Since many of the documented tench introductions started with dense populations in farm ponds, sampling of ponds in close proximity to watersheds at risk of invasion is recommended. Monitoring collaborations with commercial fishermen in the St. Lawrence River and the Great Lakes, in areas suitable for tench, such as the MFFP's network for Early Detection of Invasive Species (Réseau de détection précoce d'espèces aquatiques exotiques envahissantes du Saint-Laurent), are particularly effective at detecting the presence of the species, owing to the high fishing effort deployed through the season by the fishermen, which is difficult and costly to replicate by regular monitoring programs. Finally, an education campaign that helps anglers, commercial fishermen, and pond owners to identify tench would facilitate early detection.

Adult tench are easily distinguishable from other Great Lakes cyprinids by their very fine scales, rounded fins (Fig. 5*a*), single pair of maxillary barbels, and their reddish-brown eye (Fig. 5*b*; Scott and Crossman 1973). They often have a conspicuous green coloration and are slimy to the touch owing to abundant mucous secretion. In adults, sex can be determined externally, as mature

Fig. 5. Characteristics identifying tench specimens. Adult tench have (*a*) small scales and rounded fins and (*b*) a single pair of barbels and a red eye. (*c*) Males have a fleshy protrusion above the pelvic fins. Juvenile tench (*f*) are often difficult to distinguish from common carp (top part of *d* and *e*). Tench (bottom part of *d* and *e*) have shorter dorsal fins, a convex shaped caudal spot, and the bottom lip is terminal. [Colour online.]



males have thickened first pelvic rays and a fleshy protrusion behind the pelvic fins (Fig. 5*c*; Beelen 2006).

It is crucial to correctly identify juvenile tench, as these are usually observed earlier than the adults at sites where tench are at low abundances, such as the front of a spreading invasion (S. Avlijaš, personal observation, 2016). When they are small (<20 mm), they are most easily confused with common carp. Both species are deeper-bodied than other cyprinids and have a dark spot at the base of the caudal fin. Adult tench also have a single pair of barbels, as do common carp–goldfish hybrids, but not common carp, which possess two pairs (Holm et al. 2009); however, this feature is very difficult to observe in small specimens, even under a dissecting microscope. The principal feature that distinguishes tench from common carp is the dorsal fin, which is much shorter in the tench (Fig. 5*e*). This feature can also be difficult to discern in small specimens, particularly when viewing them in the field, and the fin is often torn during attempts to examine it (Fig. 5*f*). In such cases, the most reliable and conspicuous feature is the caudal spot, which has a convex shape in tench but is concave in common carp (Fig. 5*e*). The mouth of the common carp is subterminal, while that of the tench is terminal (Scott and Crossman 1973; Fig. 5*d*). Other cyprinids in the Great Lakes are more slender-bodied or lack the dark caudal spot (Hubbs et al. 2004). Without careful examination, very small tench might also be confused with suckers (Catostomidae); however, the latter are easily distinguished by their thick lips and subterminal sucker mouth (Scott and Crossman 1973).

Management

Relevant binational, national, state, and provincial regulations and policies

In the Great Lakes basin, possession of tench is currently prohibited by state regulations in New York, Ohio, and Wisconsin. Most Great Lakes states and provinces have general regulations that restrict the movement of aquatic invasive species (AIS) via baitfish use. To prevent AIS spread, Quebec has recently announced a total prohibition on the use of live fish as bait. In Ontario, possession of tench is prohibited under the Ontario Fishing Regulations. Tench is identified as an invasive species in the province in the *Field Guide to Aquatic Invasive Species* (Lui et al. 2010) and the Invading Species Awareness Program (http://www.invadingspecies.com/tench/; accessed 31 October 2017). However, it was not included in the recently passed provincial Invasive Species Act 2016, which covered only members of the snakehead family (Channidae) and species listed by the Council of Great Lakes Governors Aquatic Invasive Species Task Force "Least Wanted Species List". Based on existing provincial AIS lists, tench was listed as potentially invasive in Manitoba, but not Ontario, under the Aquatic Invasive Species Regulations, which were added in 2015 to the revised federal *Fisheries Act*.

Despite the potential risk, tench is not included in the Great Lakes Aquatic Nuisance Species Information System (www.glerl.noaa.gov/res/Programs/glansis; accessed 19 April 2017), the Council of Great Lakes Governors Aquatic Invasive Species Task Force "Least Wanted Species List" (http://www.cglslgp.org/projects/aquatic-invasive-species; accessed 19 April 2017), or the *Field Guide to Fish Invaders of the Great Lakes Region* (Anderson et al. 2008). Conversely, it is identified as a potential invader in the *Field Guide to Ontario Freshwater Fishes* (Holm et al. 2009), but this guide provides no information on how to identify juveniles.

Recommendations

Actions to manage newly discovered invasive species should be based on where the species is assumed to be on the invasion curve — a logistic curve representing its population growth (Blackburn et al. 2011). When invasive species are at the base of the curve, there is a narrow window of opportunity to eradicate the species. Control becomes increasingly difficult and expensive as further population growth and spread occurs; the cost–benefit ratio for prevention is much greater than for postestablishment management (Leung et al. 2002). In the past, responses to new invaders in the Great Lakes have been slow or nonexistent, resulting in high costs associated with impacts (e.g., round goby (*Neogobius melanostomus*), zebra mussel (*Dreissena polymorpha*)) and control (e.g., sea lamprey, zebra mussel). Comprehensive actions should be implemented immediately to prevent the tench's establishment in the Great Lakes basin. Uncertainty in some risk assessments should not delay such actions (Locke et al. 2011), which should include the following goals:

1. Develop and implement early detection plans (Locke et al. 2011) based on conventional (e.g., Marson et al. 2016) and eDNA (Jerde et al. 2011) methods at the invasion fronts (e.g., upper St. Lawrence) and where it has been newly reported (e.g., Lake St. Francis, Ganaraska River). The plans should include details on sampling protocols (gear, effort), frequency, and locations.
2. Develop and implement a rapid response plan (e.g., Locke et al. 2011; ACRCC 2016), including methods to eradicate, control, and prevent spread of tench.
3. Reduce the propagule pressure at the invasion front (e.g., Tsehaye et al. 2013) in the St. Lawrence River to reduce probability of spread.
4. Evaluate and implement methods to prevent the spread of tench through locks (e.g., USACE 2017), such as those found in the St. Lawrence Seaway and Champlain Canal.
5. Enforce existing federal, state, and provincial regulations on illegal stocking, AIS, and bait.
6. Add tench to federal, state, and provincial AIS regulations that prohibit possession and sale, watch lists, and AIS guides.
7. Educate commercial fishers, anglers, farmers, and the general public about the risks associated with AIS (Drake et al. 2015; Sharp et al. 2017), including tench.

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Appendix A

Appendix Table A1 appears on the following page.

Table A1. Risk assessment of tench (*Tinca tinca*) in the Great Lakes basin based on the Fish Invasiveness Scoring Kit (FISK) (Copp et al. 2009).

	Question	Answer
A. Biogeography		
1.01	Is the species highly domesticated or cultivated for commercial, angling, or ornamental purposes?	Y
1.02	Has the species become naturalized where introduced?	Y
1.03	Does the species have invasive races–varieties–subspecies?	Y
2.01	Is species reproductive tolerance suited to climates in the Great Lakes (0, low; 1, intermediate; 2, high)?	2
2.02	What is the quality of climate match data (0, low; 1, intermediate; 2, high)?	2
2.03	What is the the broad climate suitability (environmental versatility)?	Y
2.04	Is the species native or naturalized in regions with equable climates?	Y
2.05	Does the species have a history of introductions outside its natural range?	Y
3.01	Has the species naturalized (established viable populations) beyond its native range?	Y
3.02	In its naturalized range, are there impacts to wild stocks of angling or commercial species?	N
3.03	In its naturalized range, are there impacts to aquacultural, aquarium, or ornamental species?	N
3.04	In its naturalized range, are there impacts to rivers, lakes, or amenity values?	N
3.05	Does the species have invasive congeners?	N
B. Undesirable attributes		
4.01	Is the species poisonous or pose other risks to human health?	N
4.02	Does the species out-compete native species?	N
4.03	Is the species parasitic to other species?	N
4.04	Is the species unpalatable to, or lacking, natural predators?	N
4.05	Does species prey on a native species (e.g., previously subjected to low (or no) predation)?	N
4.06	Is the species a host and (or) vector for recognized pests and pathogens, especially non-native?	Y
4.07	Does the species achieve a large ultimate body size (i.e., >10 cm fork length) (more likely to be abandoned)?	Y
4.08	Does the species have a wide salinity tolerance or is euryhaline at some stage of its life cycle?	Y
4.09	Is the species desiccation-tolerant at some stage of its life cycle?	Y
4.10	Is the species tolerant of a range of water velocity conditions (e.g., versatile in habitat use)?	N
4.11	Does feeding or other behaviours reduce habitat quality for native species?	N
4.12	Does the species require minimum population size to maintain a viable population?	Y
C. Biology–ecology		
5.01	Is the species piscivorous or a voracious predator (e.g., of native species not adapted to a top predator)?	N
5.02	Is the species omnivorous?	Y
5.03	Is the species planktivorous?	Y
5.04	Is the species benthivorous?	Y
6.01	Does the species exhibit parental care of eggs and (or) young and (or) is known to reduce age-at-maturity in response to environment?	N
6.02	Does the species produce viable gametes?	Y
6.03	Does the species hybridize naturally with native species (or use males of native species to activate eggs)?	N
6.04	Is the species hermaphroditic?	N
6.05	Is the species dependent on the presence of another species (or specific habitat features) to complete its life cycle?	N
6.06	Is the species highly fecund (>10 000 eggs·kg^{-1}), iteropatric, or have an extended spawning season?	Y
6.07	What is the minimum generation time?	2
7.01	Are its life stages likely to be dispersed unintentionally?	Y
7.02	Are its life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)?	Y
7.03	Are its life stages likely to be dispersed as a contaminant of commodities?	N
7.04	Does natural dispersal occur as a function of dispersal of eggs?	N
7.05	Does natural dispersal occur as a function of dispersal of larvae (along linear and (or) "stepping stone" habitats)?	N
7.06	Are juveniles or adults known to migrate (spawning, smolting, feeding)?	N
7.07	Are eggs dispersed by other animals (externally)?	N
7.08	Does the species have density-dependent dispersal?	Y
8.01	Are any life stages likely to survive out of water transport?	N
8.02	Does the species tolerate a wide range of water quality conditions, in particular oxygen depletion and high temperature?	Y
8.03	Is the species susceptible to piscicides?	Y
8.04	Does the species tolerate or benefit from environmental disturbance?	Y
8.05	Are effective natural enemies present in Great Britain?	Y

Total score	22	
Outcome	Reject	
Section	Questions answered	Satisfy minimum requirements?
A	13	Yes
B	12	Yes
C	24	Yes
Total	49	Yes