

Identified invasion pathways of aquatic invasive alien species of EU concern to Finland with a case study of pumpkinseed (*Lepomis gibbosus*)

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Invasive alien species (IAS) are a major threat to biodiversity globally. Recognition of invasion pathways is crucial for prohibiting the introduction and spread of IAS. We reviewed invasion pathways identified for the aquatic IAS of European Union (EU) concern to Finland. Of the 36 aquatic IAS of EU concern, four (*Lepomis gibbosus*, *Pacifastacus leniusculus*, *Elodea nuttallii* and *Lysichiton americanus*) have established into nature. Escape from confinement, especially from aquariums, was recognized as the most common invasion pathway. Contamination, stowaways and corridors were regarded mainly as potential invasion pathways but rarely detected in Finland. Intentional release has been a known invasion pathway for few IAS including pumpkinseed (*L. gibbosus*), which has extended its distribution in southwestern Finland during the last ten years. The first observations of pumpkinseed were conducted by citizens, underlining the importance of public awareness raising as a management measure for all aquatic IAS. In addition, effective monitoring of the distribution of aquatic IAS using both citizen science and systematic research should be ensured.

Introduction

Globally, invasive alien species (IAS) represent one of the major threats to biodiversity, causing severe ecological, social, and economic impacts. Recognition of invasion pathways is a key to prevent the introduction and spread of aquatic IAS and to identify management options. According to EU regulation, each member state is required to conduct an analysis of invasion pathways and establish an action plan to the identified priority pathways for IAS of EU concern (EU Regulation no. 1143/2014).

For the IAS of EU concern, the pathway analyses should be made according to The Conven-

tion on Biological Diversity (CBD) classification (CBD 2014). The CBD classification divides the pathways of introduction and spread into six categories, which are further divided into 44 pathway subcategories. CBD classification framework is a robust, hierarchical system suitable for the classification of alien species introduction and spread across a wide range of taxonomic groups and environments (Pergl *et al.* 2020).

Here, we reviewed the invasion pathways of aquatic IAS of EU concern to Finland based on national IAS management and pathway action plans (e.g. Huusela-Veistola *et al.* 2017). Intentional spreading of IAS has appeared to be an important pathway for aquatic IAS (Nunes *et al.*

2015). High number of invasion pathways can be assumed to facilitate the northward range expansion of IAS. Here, we explore the risks of intentional spreading of aquatic IAS to river and lake systems using an example of pumpkinseed (*Lepomis gibbosus*) in Finland.

Prioritization of invasion pathways

In Finland, analysis of the invasion pathways and the action plans for priority pathways have been conducted separately for the first list of IAS of EU concern and for each amendment of the list (Huusela-Veistola *et al.* 2019; Huusela *et al.* 2021, 2023; MMM 2021). In the first pathway action plan, the pathways were identified and categorized according to the European Alien Species Network (EASIN) classification system, whereas in the following action plans the pathway analysis have been made according to the CBD classification (see Tsiamis *et al.* 2017 for comparison of classifications).

Here, we have unified the data from all the national pathway analyses and used the CBD classification for the species of the first EU list, as well. In addition, we have updated the information on the occurrence and pathways for two of the IAS of EU concern (*Elodea nuttallii* and *Perccottus glenii*) that have been detected in Finland after the publication of the pathway action plans. The invasion pathways have been separated into known pathways already detected in Finland and the potential pathways identified as possible pathway elsewhere. All the CBD pathways of introduction and spread of IAS were ranked according to their species volume, i.e. the number of species per pathway. In addition, the main pathways were addressed based on the establishment status of each aquatic IAS of EU concern.

Of the 36 aquatic IAS of EU concern, four have been established into Finnish nature: *Lepomis gibbosus*, *Pacifastacus leniusculus*, *Elodea nuttallii* and *Lysichiton americanus*. Three aquatic IAS of EU concern have been observed occasionally in nature in Finland: *Perccottus glenii*, *Pistia stratiotes* and *Trachemys scripta. Eriocheir sinensis* has been regularly detected in the Baltic Sea, but it cannot establish due to low salinity. Of the EU listed aquatic species, 13 have been kept

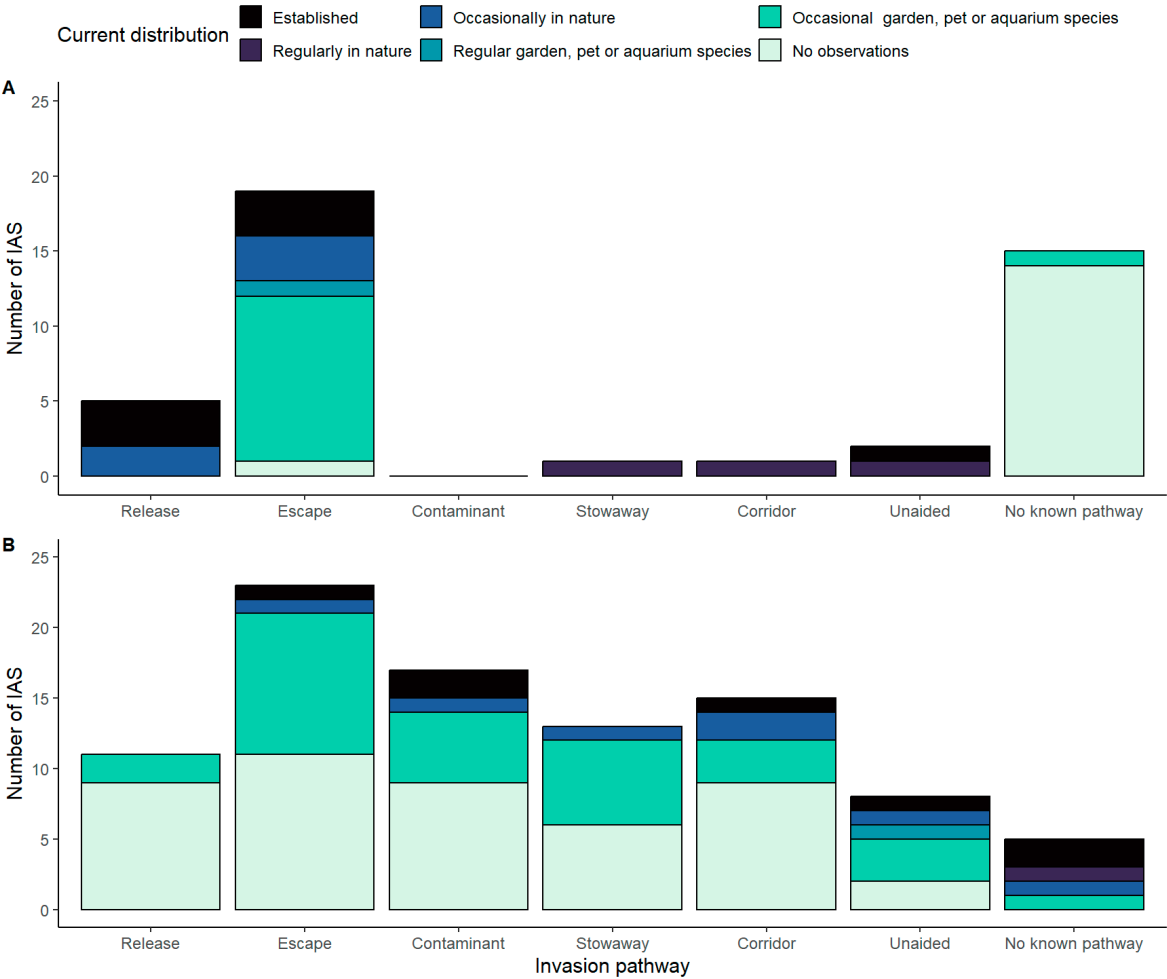
as aquarium species, and 15 have not been detected in Finland.

The most detected known and potential pathway for aquatic IAS was escape from confinement (Fig. 1) as most of the species were introduced to Finland as aquarium species. Release into nature for fishery purposes was a known pathway for two established species. The most concerning pathway is other intentional release into nature, through which possibly two occasional (*Perccottus glenii* and *Pistia stratiotes*) and two established species (*Elodea nuttallii* and *Lepomis gibbosus*) have spread in Finland. Contaminant was not identified as a known pathway, but it was identified as potential pathway especially as contaminant on plants, animal or baits. In addition, unintentional introduction as stowaways or through interconnected waterways or seas were rarely identified as known pathways but were often recognized as potential pathways. In marine environment most often aquatic IAS could potentially be introduced as stowaways by fishing equipment or by ships through ballast water or hull fouling.

Intentional release of pumpkinseed as a concern

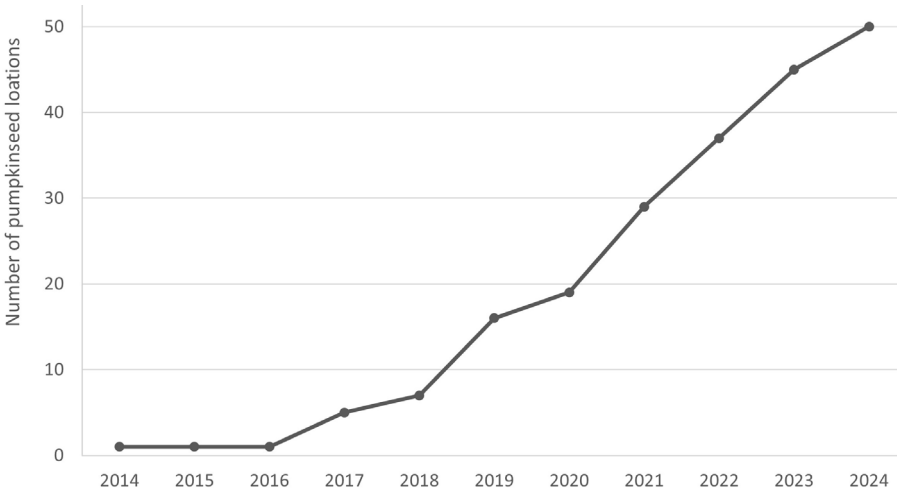
The pumpkinseed is a freshwater fish belonging to the family Centrarchidae and is native to eastern North America (DG ENV 2023). It has been introduced widely elsewhere in North America, in addition to Europe as early as the late 1800s (Hanel *et al.* 2011). Preferred habitats for pumpkinseed are ponds, reservoirs and lakes. As a versatile user of food resources, as well as a defender of its food territory, the species survives in many environments and competes with native species (Almeida *et al.* 2014; Copp *et al.* 2017). Pumpkinseed has a great capacity for reproducing and individuals released into the wild have formed permanent populations (Jordan *et al.* 2009). Pumpkinseed has been considered as a species capable of altering the ecosystem after it has been introduced (DG ENV 2023).

The pumpkinseed was first recorded in a small pond in southwest Finland in 2014. In the last ten years, the known locations of the pumpkinseed have increased to 50 (Fig. 2); these lo-



▲ Fig 1. A) Known and B) potential invasion pathways for aquatic species of EU concern according to their current distribution status.

► Fig 2. Known pumpkinseed (*Lepomis gibbosus*) locations in Finland have increased through a ten-year period 2014–2024.



cations are strongly concentrated in southwestern Finland. Typical locations for the pumpkinseed are small ponds, sand pits and quarries. The knowledge of the pumpkinseed locations is gathered through citizen science reporting (vierasla-jit.fi). Habitat types and locations of the known sightings of pumpkinseed indicate that this species has arrived and spread by illegal intentional release.

Discussion

Escape from captivity and deliberate release appeared to be the most common detected invasion pathways for aquatic IAS of EU concern in Finland. This is in line with previous studies on the main pathways of introductions of freshwater alien species in Europe (Nunes *et al.* 2014). Specifically, escape and release through aquaculture, aquarium trade, fisheries and angling have been recognized as the most important pathways of introduction in Europe (Hulme *et al.* 2008, Nunes *et al.* 2014). Although stowaways, such as shipping, and corridors are major pathway for many marine species in Europe (Katsanevakis *et al.* 2013), in Finland they were usually identified only as potential pathway for IAS of EU concern. Currently, the national as well as EU legislations prohibit the spread and intentional release of IAS in the EU. National action plans on invasion pathways are obligatory for EU member states. They can be a powerful tool to manage pathways and prevent unintentional spread along the pathways (e.g. Mayer *et al.* 2023).

Despite the national and EU legislations, the pumpkinseed has been spreading to at least 50 locations in Finland. As the presence information is based solely on citizen science and is lacking more systematic research data, the actual pumpkinseed location number can be higher than reported here. Currently, the known locations have been mostly closed ponds and quarries. Concerns arise from the scenario of the pumpkinseed spreading to rivers and large lake systems, with potentially serious consequences to local biodiversity and ecosystem services, as has been realized elsewhere in Europe (Copp *et al.* 2017). Due to climate change and warming water temperatures pumpkinseed can also get resource

competition benefits compared to local fish species (Fobert *et al.* 2011). Eradication of any IAS from the large lakes is not feasible and these habitats offer vast opportunities for the pumpkinseed to thrive. Eradication of pumpkinseed has so far been carried out in two smaller ponds in southern Finland. Emptying and dredging of a pond was made in Paimio during 2023–2024. Eradication of pumpkinseed seems to have been successful. However, the *Elodea nuttallii* has reappeared in the pond while it has been left to fill with rain and runoff. The cost of the eradication was approximately 200.000 €. Eradication of pumpkinseed in Espoo with rotenone was carried out in August 2025 and success of this effort is still being evaluated.

Intentionally released aquatic IAS to Finland included fishes, amphibians and aquatic plants, with the areal focus in southwestern Finland. The first observations of many of these species – including pumpkinseed – were made by citizens. In Finland, citizens can report their observations through an online platform and observations are verified by experts. Information on IAS occurrence obtained by citizen science is in a central role in aquatic IAS monitoring in Finland (Lehtiniemi *et al.* 2020).

The results suggest that a key management measure for the spread of IAS of EU concern in Finland is the prevention of escape under human control. This calls for both general communication for the increase of public awareness and targeted communication on the release of aquarium species into nature. Effective monitoring of the distribution of aquatic IAS requires for both citizen science and systematic mapping with the addition of e.g. eDNA methods.

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