https://doi.org/10.59893/abud.24(1).002

Acta Biol. Univ. Daugavp. 24(1) 2024
ISSN 1407 - 8953

FISH INTRODUCTION IN LATVIA- INVENTORY, PRESENT STATUS AND PROSPECTS

Jānis Birzaks*

Birzaks J. 2024. Fish introduction in Latvia – inventory, present status and prospects. *Acta Biol. Univ. Daugavp., 2024(1): 9-28.*

Abstract
The article reviews the history of fish introductions in Latvia, their aims and results, their potential impact on the local ichthyofauna and future prospects. There have been three periods of fish introductions in Latvia: a) from the Middle Ages to the 1940; b) from 1940 to 1990; c) from 1990 to the present. The peak of fish introductions occurred after the Second World War until 1990. Most of these species originate from the European and Asian part of the former USSR. A total of 28 fish species have been introduced in Latvia; of these, four species have naturalized. Only two of the introduced species are now relatively widespread, while one is invasive. Aquaculture and fish stocking to establish new fisheries were the key drivers for the introduction of non-native species in Latvia. These attempts in Latvia have largely failed. Aquaculture is the only fishery sector in Latvia that has benefited from fish introductions in terms of increased diversity production. Our results show that the impact of earlier introductions in Latvia has so far not had a significant impact on native species and biodiversity. However, taking into account the possible effects of climate change in interaction with anthropogenic modifications, it could increase: a) with the introduction of new species from neighbouring countries and b) with the establishment of self-sustaining populations.

Keywords: Latvia, introduced fishes, freshwaters, impacts, management

*Corresponding author: *Jānis Birzaks. Institute of Life Sciences and Technology, Vienības Str. 13, Daugavpils LV- 5401, Latvia, E-mail: janis.birzaks@du.lv*

INTRODUCTION

Fish are simultaneously one of the most introduced (Holčik 1991, Welcomme 1992, Gozlan 2008) and most threatened animal groups (Moyle 1986, Gozlan et al. 2010). Fishes are economically important and their introduction has generally been targeted for economic gains.

In Europe, the introduction of fish began with the spread of Christianity (Balon 1995), continued in the 15th- 16th centuries (Clavero 2022), but on a larger scale began in the 19th century with the development of artificial fish farming technologies and improvements in the transport of alive fish (Moyle 1986, Welcomme 1992). After World War II, it increased, declining substantially from the 1990s (Welcomme 1992, Britton & Gozlan 2013). In Latvia, the introduction and translocation of non- native fish species was a common fisheries management practice from the 19th century onwards (Andrušaitis 1960, Aleksejevs & Birzaks 2011), which has persisted to some extent today.

The introduction of species has always carried a certain risk. As a result, introductions can continue with biological invasions, one of the main threats to biodiversity worldwide (Cambray 2003, Gozlan et al. 2010, Britton et al. 2019, Su et al. 2021, Bernery et al. 2022). However, it was and remains the most important driver of aquaculture development (De Silva et al. 2006, Gozlan 2017). Therefore, although the negative impacts of introduced fish species are well known, introductions are still made to create new food fisheries (commercial or recreational) or to introduce new species into aquaculture or as pets (Holčik 1991, Welcomme 1992).

The impacts of global change on freshwater fish fauna suggest that a northward shift of species has begun and will continue (Rolls et al. 2017). The major threats to freshwater biodiversity are pollution and eutrophication (Dudgeon et al. 2006), habitat conversion (Moyle & Light 1996, Cambray 2003), removal of geographical barriers (Semenchenko et al. 2011, Rabitsh et al. 2013) and biological invasions (Gozlan et al. 2010; Souza et al. 2022). Their interaction with global climate change impacts such as increased temperature (Carpenter et al. 2011, Rolls et al. 2017, Osland et al. 2021) and altered hydrological regimes (Barbarossa 2021) will create new opportunities for successful future invasions of introduced species (Carosi et al. 2023).

The objectives of this study are: 1) to compile a list of fish species introduced into Latvia; 2) to assess their population status; and 3) to evaluate the results of their introduction, recent use; 4) a brief assessment of the prospects for future introductions.

MATERIAL AND METHODS

Data collection and inventory

The article draws on popular and scientific publications from the 19th century to the present, Archives and reports of the former Baltic Fish Conservation and Propagation Authority on commercial and recreational fishing and fish restocking in Soviet period 1949-1990. Recent data on aquaculture, commercial and recreational fisheries, restocking, and inventory compiled and provided by the Scientific Institute for Food Safety, Animal Health, and the Environment BIOR and summarised in the Latvian Fisheries Yearbooks and on the publicly accessible website https://bior.lv/lv. In total, fishing, restocking and inventory data covered 1097 lakes, 435 rivers and 277 reservoirs in Latvia.
The scientific names used in this article are in accordance with the Handbook of European Freshwater Fishes (Kottelat & Freyhof 2007).

Terms and terminology

We consider an introduction to be the intentional or unintentional introduction or translocation of a species by humans into geographic areas (excluding areas completely isolated from the natural environment) where the species (taxon) has not previously occurred (Welcomme 1988, Copp et al. 2005). We do not consider as introduced native species that have been moved within the country to watersheds where they have not been present for some reason (Holčík 1991).

After introduction species may survive at least part of their life cycle in a new environment and climate, unable to establish self-sustaining populations without human assistance (casual species), or naturalize, establishing self-sustaining populations (naturalized species) and integrating into the native biota (Scalera & Zaghi 2004).

In the former USSR, which included Latvia from 1940 to 1990 (called the Soviet period) different terminology was used. The release of native fish species into water bodies where they did not occur was called introduction. The introduction and release of alien species into natural waters were called acclimatization

(Kuderskii 2001). These differences in terminology were taken into account when we used and cited Soviet period sources.

RESULTS AND DISCUSSION

In total 28 species (Tab. 1) have been introduced into Latvian inland waters, of which four have naturalised. They represented 9.5% of the Latvian freshwater fish fauna, which includes 42 fish and lamprey species (Aleksejevs & Birzaks 2011).

The species attempted to be introduced into Latvia belong to six families - Acipenseridae (five species), Eleotridae (one species), Coregonidae (nine species), Cyprinidae (six species), Moronidae (one species) and Salmonidae (six species). They originate from Europe (nine species), Asia (fifteen species) and North America (four species). They originate from Europe (nine species), Asia (fifteen species), and North America (four species). Germany, Russia and Sweden were the donor countries initially, followed by the USSR and China, and after 1990 Russia, Scandinavian countries and Poland. Four species Peipsi whitefish *Coregonus maraenoides,* peled *Coregonus peled,* gibel *Carassius gib*elio and Amur sleeper *Percottus glenii,* were naturalized. All of non- native species except Amur sleeper were deliberately introduced.

History of fish introduction

The introduction of fish into Latvia can be divided into three periods: 1) from the Middle Ages to 1940, 2) the Soviet period from 1940 to 1990, when Latvia was occupied and incorporated into the USSR, and 3) from the 1990s to the present.

Six fish species were introduced into Latvia during the first introduction period (Appendix 1). Carp is believed to have been cultivated in ponds belonging to monasteries from the 13th century (Andrušaitis 1960). Their release into natural waters began on a large scale in the 1950s. So far, carp have been released into 230 lakes, 3 rivers, and 35 reservoirs. No self-sustaining carp populations have been established in Latvia. Their presence in natural water bodies is the result of stocking or occasional escapes from hatcheries ponds.

In the 19th century sterlet *Acipenser ruthenus* (Linnaeus, 1758) and trout (species not specified) were reared in ponds (Bertrams 1883, Bertrams 1888). The first species to be introduced directly into natural waters seems to have been the sterlet in 1885 (Sapunov 1893). Repeated attempts were made to introduce this species in the 1950s and 1970s. Rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) was introduced in 1899 and released in "private streams" (Eglītis 1939b). They have been regularly released in the rivers, reservoirs, lakes, and coastal waters of the Gulf of Riga since the 1960s, peaking in the 1980s (Mittans et al. 1993). There was also a large escapement of rainbow trout from aquaculture enterprises in the Gulf of Riga in the late 1980s (ICES WGBAST 1995). Attempts to introduce this species into natural waters have been unsuccessful. However, nowadays its stocking takes place mainly for recreational fishing (“put and take”) or angling competitions. From the 1980s to the 1990s, the species was widely farmed in aquaculture. After the collapse of the USSR, aquaculture in Latvia was in a state of depression and, accordingly, rainbow trout production declined to five t/year (instead of 150 t in late 1980s). Since 2014, it has recovered to rank second in aquaculture production in Latvia, averaging 80 t/year.

Peipsi whitefish *Coregonus maraenoides* (Polakov, 1874) was the most widely artificially distributed species in the first period, being released in at least 30 lakes. They were also released in the second period, in a total of 67 lakes and two reservoirs (Appendix 1). Already in the 1930s, it was found that the species was able to acclimatize to Latvian lakes, but its populations were largely able to persist only with human support (from Copp et al. 2005 casual taxa). So far, self-sustaining populations have been found in two lakes (Andrusaitis 1960, Aleksejevs & Birzaks 2012).

The brook trout *Salvelinus fontinalis* (Mitchill, 1814) was introduced in 1902, 1912. 1914. No known locations of introduction have been reported (Zandbergs 1940). The introduction of the species into the wild has failed.

The introduction of the fish into Europe peaked in the 1960s (Holčík 1991, Welcomme 1992, Kuderskii 2001, Copp et al. 2005). In Latvia, the highest number of alien species was introduced between 1940 and 1990 (second period) - 21 species (Appendix 1, Tab. 1). Most of the species introduced during this period were from the European and Asian parts of the former USSR. The origin of introduced species differed from those in Western Europe in terms of their place of origin due to limited economic relations (Britton & Gozlan 2013).

In 1948 the Prussian carp *Carassius gibelio* (Bloch, 1782) was introduced into Latvia in fishponds and stocked in lakes and reservoirs. In total, it has been released into 214 lakes and 11 reservoirs. It is also widespread in the coastal waters of the Gulf of Riga (Vetemaa et al. 2005). Prussian carp catch in commercial, subsistence, and recreational fisheries has averaged three t/year since 2000.

From 1953-1963 seven species of the Coregonidae were introduced from Russia: ripus *Coregonus ladogae* (Pravdin, Golubev & Belyaeva, 1938), Ludoga *Coregonus luttoka* (Kottelat, Bogutskaya, & Freyhof, 2005), Baikal cisco *Coregonus migratorius* (Georgi, 1775), inconnu *Stenodus nelma* (Pallas, 1773), peled, *Coregonus peled* (Gmelin, 1789), broad whitefish *Coregonus nasus* (Pallas, 1776), volkhov witefish *Coregonus baerii* (Kessler, 1864).
Peled were the most widespread, introduced into more than 50 lakes and farmed in ponds. The species acclimatized, but populations were mostly short living. It naturalized only in two interconnected lakes in the Venta River basin, establishing a small self-sustaining population (Aleksejevs & Birzaks 2012).

From 1970 to 1980, peled was cultivated in pond farms and lakes, producing an average of 1.5 t/year. Diplostomiasis (its acute form cercariosis) was the most common disease of Coregonidae and was a major factor in the failure of the introduction of this species into pond aquaculture, lakes and reservoirs (Rumiantsev 1978).
The introduction of the other Coregonidae species mentioned above was not successful. Currently, occasional introductions of Coregonidae species are made both in lakes and rivers. Their taxonomic affiliation is usually unknown, as 'whitefish' are reported in stocking protocols. However, they are generally released in relatively small numbers and are not currently cultured in aquaculture in Latvia.

The striped bass *Morone saxatilis* (Walbaum, 1792) was introduced into Latvia in 1964 and released once into a separate lake in 1972. There are no known catches of this species neither commercial nor recreational fisheries.

In the 1970s, 4 species of Asian Cyprinidae ("Chinese carps") were introduced into Latvia: the grass carp *Ctenopharyngodon idella* (Valenciennes, 1844), the black carp *Mylopharyngodon piceus* (J. Richardson, 1846), bighead carp *Hypophthalmichthys nobilis* (J. Richardson, 1845) and silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844). Grass carp and silver carp were also released into natural waters. These species did not breed under Latvian conditions. In the 2000s, grass carp were cultivated in small quantities - 0, 5-4 t per year in polyculture together with carp in pond farms.

The introduction of all the above species into natural water bodies has now ceased. However, grass carp are introduced into private ponds for plant control unauthorized. Their juveniles are offered and can be freely purchased.

In the 1980s, three species of Acipenseridae were introduced into Latvia to restock natural waters: the beluga *Huso huso* (Linnaeus, 1758), the Russian sturgeon *Acipenser gueldenstaedtii* (von Brandt & Ratzeburg 1833) and the Siberian sturgeon *Acipenser baerii* (J. F. Brandt, 1869) (Surin et al. 1967, Kairov 1968). The Russian and Siberian sturgeon were able to acclimatize, but their releasing was stopped. From the late 1990s, aquaculture of these species started, averaging 36 t/year in 2007. They are released in small quantities for recreational "put&take" fishing in private water bodies.

In the 1980s, attempts were made to introduce Pacific salmon species, Chum salmon *Oncorhynchus keta* (Walbaum, 1792) and pink salmon *Oncorhynchus gorbuscha* (Walbaum, 1792), into 7 rivers, releasing their larvae and juveniles (Rimsh 1977). At the same time, aquaculture of the coho salmon *Oncorhynchus kisutch* (Walbaum, 1792) was initiated. It was also released in two lakes and the Gulf of Riga. Catches of individual specimens were reported one year after release. However, the introduction of this species into both aquaculture and natural waters was not successful.

The only species that was introduced in Latvia unintentionally was the Amur sleeper *Percottus glenii* (Debowsky, 1877), which was first recorded in Latvia in 1974. This species was first recorded in a pond in an urban area (Pupiņa et al. 2015), which most likely indicated a stocking from an aquarium. The unauthorized release of Amur sleeper continues. The species now is found throughout the country, often in isolated, small water bodies where it could not naturally migrate through the river network.

Since 1990 (third period), only one species Atlantic sturgeon *Acipenser oxyrinchus* (Mitchill, 1815) has been introduced into Latvia. From 2013, it has been stocked into the estuaries of the Daugava and Gauja rivers. Some specimens were caught as by-catch in coastal fisheries, mainly in the Gulf of Riga.

Objectives, rationale and results of fish introductions

The goals and motivation of the introduction of non-native fish species have been very diverse. In Eastern Europe, it has typically been carried out through the introduction of new species for aquaculture, supplementation of existing stocks with new species for fisheries or angling purposes, ornamental and aquarium purposes, accidental releases, biomanipulations and unknown ("trivial") reasons (Holčik 1991, Copp et al. 2005).

The first hatchery in Latvia was established in 1885 (Eglītis 1939a), followed by several others built between then and 1939. In 1929, a state-owned and subsidized hatcheries was established, several of which still exist today. Their main function was the rearing of juveniles of native fish species for restocking, as well as the hatching of non-native fish species (Andrušaitis 1960).

The primary purpose of the introductions was to contribute to local fish stocks, mainly for food fisheries. It was believed that artificially propagated stocks of introduced fish would allow commercial fishing without restrictions (Eglītis 1939a). Similar practices were common in the species-poor temperate areas of Europe, which were subject to glaciation during the last ice age (Welcomme 1992). In Latvia, attempts to introduce non-native species in the period up to 1940 did not achieve the expected results, in some cases casual Peipsi whitefish populations established (Eglītis 1937c). Introductions rate in Latvia during this period were relatively low (Tab. 1).

Table 1. Stocking of non- indigenous fish in waterbodies by periods.

	Type of waterbody			Rate of introduction	
Period	Lakes	Rivers	Reser-voirs	Number of stoc-kings	Number-of intro-duced species
<1940	38	14	0	116	6
1941-1990	308	16	40	2007	21
>1990	66	10	19	233	1

After Latvia's occupation and incorporation into the USSR in 1940 and until its collapse in 1990-1991 (second period), the most extensive introductions were carried out. This was largely driven by the post-war recovery and ambitious plans of hydropower development in the region (Pischula1950, Malikova 1966). It was predicted that losses to fisheries would be unavoidable and significant, especially for diadromous fish species. The runoff of biogenic elements into the Gulf of Riga was predicted to change, affecting its biological productivity (Malikova 1966). The objectives of the introduction were to compensate losses and/or obtain new food fisheries. The introduced species will play an important role in replenishing or replacing native stocks, especially diadromous fish, which will be largely lost (Malikova 1966, Surin et al. 1967, Golovkov & Kuzmin 1969, Rimsh 1977). The introduction was in a campaign-like manner (Berka 1990, Kuderski 2001).

Since 1990, fish introductions have declined significantly, with only one species being introduced into Latvia (Appendix 1). This was linked to the sturgeon recovery plan in the Baltic Sea basin, when Atlantic sturgeon stocking material was imported from Canada (Gessner et al. 2019).

However, there are several uncertainties regarding the recovery of the sturgeon population in the Baltic Sea basin. The taxonomic affiliation of the Baltic sturgeon population is unclear. Until the beginning of the 21st century, the Baltic Sea basin was thought to be inhabited by the sturgeon *Acipenser sturio*. However, more recent genetic studies have concluded that *A. oxyrinchus* has not replaced *A. sturio*. The Atlantic sturgeon was originally the first species of Acipenseridae to colonize the Baltic Sea basin. It introgressed with *A. sturio*, later forming a hybrid Baltic sturgeon population (Ludwig et al. 2002, Tiedemann et al. 2007, Popovic et al. 2008, Popovic et al. 2014), which later became extinct due to various reasons, including anthropogenic influences. In the context of the Baltic Sea, stocking the sturgeon population with fish of Canadian origin is the introduction of a non-native species, which would perhaps fill the ecological niche of a lost native species.

In most cases, the introduced species failed to reproduce and disappeared from the recipient biota. Acclimatization does not necessarily result in increased fisheries and economic benefits. In the former USSR, which was a leader in fish introductions in Europe, only 3% of the stocking of alien fish resulted in a significant increase in commercial catches (Lifshits & Belousov 1979). The results of the introduction and subsequent acclimatization were often over-optimistic and did not match the results. The cost of implementation efforts exceeded the results, mainly due to an insufficient biological basis and deficiencies in actual practice and organization. In general, the introduction of only a few species into natural waters resulted in economic benefits (Holčik 1991).

Catches of introduced species in commercial, subsistence and recreational fisheries accounted for only 0.3% of total catches from 1946 onwards, only reaching 3% in some years (Fig. 1).

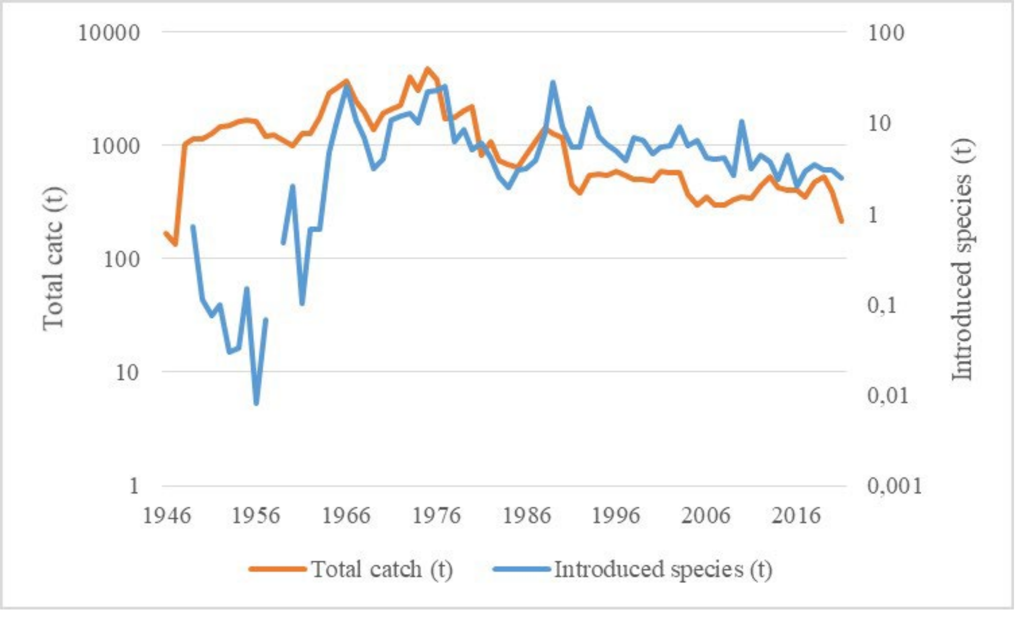

Figure 1. Total catches and catches of introduced species in Latvian inland waters (t).

Stocking of Coregonidae family species resulted in the establishment of two small and economically insignificant populations of Peipus whitefish and peled (Aleksejevs & Birzaks 2012). Stocking of Pacific salmon, rainbow trout, and Acipenseridae family fish proved to be a very low capture rate in the fishery (Kairov 1968, Rimsh 1977; Mitans et al. 1993). Overall, the introduction of alien species into natural waters of Latvia has failed. The introduction and release of non-native species into Latvia's inland waters has not brought economically significant benefits to fisheries. Of the 28 species introduced, only four have naturalized (Annex 1).

In contrast to the generally ineffective introduction of fish by stocking in the wild, some species have become beneficial in aquaculture. Latvia's modern aquaculture structure was established after the collapse of the USSR in 1991. Total aquaculture production, driven by carp farming in ponds, fell from 2000 to 500 t. In addition to the carp and rainbow trout farmed during the Soviet period, the Acipenseridae (Siberian sturgeon, sterlet, and hybrid bester) and Salmonidae (artic charr) were introduced, while peled farming was discontinued. Aquaculture is the only fishery sector in Latvia that has benefited from fish introductions in terms of increased diversity of production (Fig. 2).

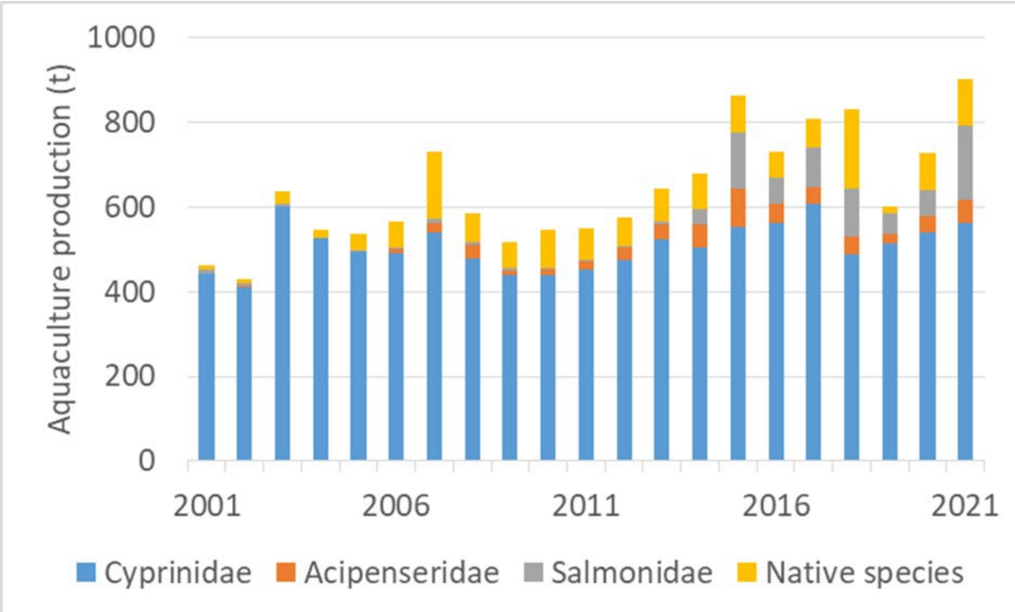

Figure 2. Aquaculture production (t) in Latvia.

Impact of introduced species

In addition to the clear benefits for aquaculture, fish introductions have had a wide range of negative impacts and associated consequences (Cucherousset & Olden 2011). The integration of an introduced species into an ecosystem is associated with risks to biodiversity through habitat modification (Brown & Moyle 1997, Koehn 2004, Pipalova 2006), predation and competition (Manchester & Bullock 2001, Bernery et al. 2022), and the spread of new diseases and parasites (Gozlan et al. 2005, Kuchta et al. 2018). The impact of alien fish species on ecosystems and biodiversity in Latvia has been poorly studied. However, it is known that most of the introduced alien species failed to naturalise in the wild and disappeared when stocking ceased (Holčik 1991).

The impact of Amur sleeper as a predator on biota has been more extensively studied (Reshetnikov 2003). It feeds on a variety of aquatic invertebrates (competition with native fish species), but its largest individuals feed on fish and amphibians. In Latvia, its impact on protected species of toads and newts has been assessed as negative. However, this effect is significant in specific habitats, small water bodies with high population densities of *P. glenii* (Pupiņa & Pupiņš 2012, Rakauskas et al. 2019, Pupins et al. 2023).

C.gibelio can cause significant changes in the structure of fish communities, becoming the dominant species. It is an important trophic competitor to native cyprinid species. The species can reproduce gynogenically and can also form hybrids with *C. carpio*, *Carassius* spp. and other Cyprinidae (Hanfling et al. 2005, Koščo et al. 2010). Recently, gibel carp has become one of the most abundant and dominant Cyprinidae species in the coastal waters of the Gulf of Riga, likely having a significant impact on food chains (Vetemaa et al. 2005).

Introduced species can carry diseases and parasites that can infect native fish species.

The eel nematode *Anguillicoloides crassus* (Kuwahara, Niimi & Hagaki, 1974) was introduced into Europe in the early 1980s as a result of the transport of eels for aquaculture in Germany (Koops & Haartmann 1989). In Latvia it was first detected in 1994 in eels caught in coastal waters, and from 1998 also in lakes. Currently, *A. crasus* is found throughout the country, including in water bodies inaccessible to upstream migrating eels from the sea. It has also been found in host fish species, mainly roach and perch (Vismanis 1998, Kirjusina & Vismanis 2000, Kirjusina & Vismanis 2007). The Asian fish tapeworm *Bothriocephalus acheilognathi* (Yamaguti, 1934) was found in carp from Latvian pond farms in 1965. The natural host of *B. acheilognathi* is the grass carp, which is native in China and eastern Russia. However, it has spread worldwide through the introduction of grass carp. *B. acheilognathi* has been reported in over 300 species of freshwater fish (Kuchta et al. 2018), infecting species of Cyprinidae, Poecilidae, Cichlidae and Centrarchidae (Marcogliese 2008). Studies show that Asian fish tapeworm causes high losses in fish farms. As it can colonize a wide range of fish hosts, the accidental introduction of infected fish poses a major risk to any freshwater ecosystem. It is suspected that it may adversely affect endangered wild species (Heckmann 2000).

CONCLUSIONS

Fish introductions have been made for many different reasons, but have mainly been driven by aquaculture (Welcomme 1992, Gozlan et al. 2005, Gozlan 2008). In Latvia, most of the non-native species were initially introduced for stocking into natural watercourses, but were subsequently reintroduced later, both for aquaculture and for release. Aquaculture also includes the trade, import, transport, and intentional or accidental release of live freshwater fish (Kerr et al. 2005, Britton et al. 2011). It is and will remain the most important pathway for fish introductions (Gozlan et al. 2010, Rabitsch et al. 2013).

Although no significant impacts of introduced fish species on biodiversity have been observed in Latvia so far, the situation may change in the future. This will be determined by the potential impacts of climate change and their interactions with anthropogenic modifications to freshwater ecosystems that have taken place in the past.
Human activity has broken down geographical barriers, connecting river basins that were once completely isolated from each other. A well-known example is the Ponto-Caspian gobies, which has been introduced into the Baltic and North Sea river basins through three invasive corridors in the Volga, Vistula and Danube/Rhine river and canal systems (Semenchenko et al. 2011). These species have reached and spread nearby Belarus (Mastitsky et al. 2010), Poland (Nowak et al. 2008), Czech Republic (Musil et al. 2010), Slovakia (Koščo et al. 2010), Austria (Wiesner et al. 2000) and Germany (Gollasch & Nehring 2006) river systems, lakes and Baltic Sea and North Sea coastal waters. The headwaters of Latvia's major rivers are located in neighboring Lithuania, Belarus, and Russia, creating potential introduction pathways.

Due to current climate change and its interaction with other natural and anthropogenic changes in freshwater ecosystems, species (including invasive) introduced and able to naturalize in milder climates are spreading northwards (Heino et al. 2009, Rahel & Olden 2008, Osland et al. 2021, Vilizzi et al. 2021, Souza et al. 2022, Carosi et al. 2023). Global projections of climate change impacts also suggest a northward shift of warm-water species (Comte et al. 2013). In Latvia, a small country in terms of area, changes in the distribution ranges and abundance of warm- and cold-water species are also being observed (Aleksejevs & Birzaks 2010, Aleksejevs & Birzaks 2011).

Species already naturalized in geographically close areas in Lithuania and Belarus could potentially be introduced or arrive in Latvia by migrating through the river network. The topmouth gudgeon *Pseudoraspbora parva* (Temminck & Schlegel, 1846), which was found in Lithuania, is expected to arrive in Latvia shortly (Rakauskas et al. 2021). Generalist species that can adapt to a wide range of environmental conditions are more likely to naturalize (Heino et al. 2009, Tonella et al. 2018). Potentially, these could be Ictiluridae (Ameiurus spp..) and Centrarchidae (Lepomis spp.) families.

Experience also shows that even the most stringent control measures have been ineffective or insufficiently effective because the pathways of spread are so diverse and often uncontrolled. Given that alien species are still being introduced for both aquaculture and fisheries enhancement, it is more likely that introductions of species, with all their consequences, will continue (Rahel 2004, Gozlan 2008, Britton et al. 2011a,b). Effective action is only possible if the species was recently introduced and has spread over a limited area. Prevention and early detection or monitoring and containment and/or eradication of introduced species at a later stage if the invasion progresses is considered an optimal management strategy (Robertson et al. 2020). However, even with the best management strategies and practices, new species will be introduced. Specific management measures for mixed fish communities will need to be developed to protect native species.

There is a need for a better understanding of the interaction between anthropogenic environmental change and climate warming on the distribution of alien species and their effects on native species, their communities, and their habitats.

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Received: 07.03.2024
Accepted: 22.04.2024

Appendix 1. List of species introduced in Latvia inland waters Present status: A- aquaculture, N- naturalised, Ex- extinct, I- invasive, Un- unknown.

Period	Year of introduction	Reason of introduction	Year of introduction, releasings	Species	Natural range	Introduciton rate	Present status
I period	13th century	Aquaculture, stocking	1928, regularly from 1946	Common carp, Cyprinus carpio, (Linnaeus, 1758)[1,3,4,5]	Europe	230 lakes, 35 reservoirs, 3 rivers	A
	1885	Stocking, aquaculture	1885, 1948, 1951- 1952, 1965	Sterlet, Acipenser ruthenus (Linnaeus, 1758)[2]	Europe, Asia	2 rivers, 1 reservoirr	A
	1899	Aquaculture stocking	1899, 1900, 1907- 1914, 1930- 1941 regularly from 1960	Rainbow trout, Oncorhynchus mykiss (Walbaum, 1792)[1,2,3,4]	North America	39 lakes, 12 rivers, 6 reservoirs, Gulf of the Riga	A
	1899	Stocking	1899, 1900-1912, 1921-1933, 1946-1971	Peipsi whitefish Coregonus maraenoides (Polyakov, 1874)[4]	Europe	67 lakes, 3 reservoirs,	N
	1902	Aquaculture	1902, 1912, 1914	Brook trout, Salvelinus fontinalis (Mitchill, 1814)[2]	North America	n.a.	A
	1940	Stocking, aquaculture	1940, 2007-2010	Arctic charr, *Salvelinus alpinus* (Linnaeus, 1758)	Europe	1 lake	Ex
II period	1948	Aquaculture, stocking	1948, regularly from 1951	Gibel, Carassius gibelio (Bloch, 1782)[1,3,4,5]	Asia	214 lakes, 11 reservoirs	N
	1954	Stocking, aquaculture	1957 – 1978, 2004 – 2009, 2011, 2012, 2013	Peled, Coregonus peled (Gmelin, 1789)[1,3]	Europe, Asia	67 lakes, 1 rivers, 3 reservoirs	N
	1955	Stocking	1955 – 1974, 1980	Ripus Coregonus ladogae (Pravdin, Golubev & Belyaeva, 1938)	Europe	1 river, 13 lakes, 3 reservoirs	Ex
	1956	Stocking	1956	Coregonus luttoka (Kottelat, Bogutskaya& Freyhof, 2005)	Europe	6 lakes, 1 river	Ex
	1957	Stocking	1957, 1960	Baikal cisco Coregonus migratorius (Georgi, 1775)	Asia	2 lakes	Ex
	1957	Stocking	1958	Inconnu, Stenodus nelma (Pallas, 1773)	Asia, North America	1 lake	Ex
	1960	Stocking	1977, 1978, 1982	Broad whitefish Coregonus nasus (Pallas, 1776)[6]	Europe, Asia,	2 lakes	Ex

					North America		
	1960s	Aquaculture, stocking	1970, 1980, 2005, 2012, 2014	Grass carp Ctenopharyngodon idella (Valenciennes, 1844)[1,3]	Asia	5 lakes, 5 reservoirs	A
	1960s	Aquaculture	n.a.	Black carp Mylopharyngodon piceus (J. Richardson, 1846)	Asia	n.a.	Ex
	1960s	Aquaculture	n.a.	Bighead carp Hypophthalmichthys nobilis (J. Richardson, 1845)	Asia	n.a.	Ex
	1960s	Aquaculture, stocking	1980, 2005, 2008, 2009	Silver carp Hypophthalmichthys molitrix (Valenciennes, 1844)[1,3]	Asia	1 lake, 3 reservoirs	A
	1962	Stocking, aquaculture	1962	Beluga Huso huso (Linnaeus, 1758)[6]	Europe, Asia	1 river	Ex
	1962	Stocking	1962- 1969	Russian sturgeon Acipenser gueldenstaedtii (von Brandt & Ratzeburg 1833)[12,,3]	Europe, Asia	3 lakes, 3 rivers, Gulf of the Riga	Ex
	1962	Stocking, aquaculture	1962- 1975	Siberian sturgeon Acipenser baerii (J. F. Brandt, 1869)	Asia	3 lakes, 3 rivers, Gulf of the Riga	A
	1963 (1949?)	Stocking		Volkhov witefish Coregonus baerii (Kessler, 1864)[1,2,3]	Europe	2 lakes	Ex
	1964	Stocking	1972	Striped bass Morone saxatilis (Walbaum, 1792)	North America, Atlantic coastline	1 lake	Ex
	1970	Stocking	1970	Chum salmon Oncorhynchus keta (Walbaum, 1792)	Asia, North America	4 rivers, Gulf of the Riga	Ex
	1970	Aquaculture, stocking	1973	Muksun Coregonus muksun (Pallas, 1814)	Asia	1 lake, Gilf of the Riga	Ex
	1973	stocking	1973- 1980	Pink salmon Oncorhynchus gorbuscha (Walbaum, 1792)	Asia, North America	7 rivers, Gulf of the Riga	Ex
	1974	Unintentional stocking	Firstly detected in 1974	Amur sleeper Percottus glenii (Debowsky, 1877)[35]	Asia	Accidental restocking	N, I

	1980	Stocking	1980, 1985	Coho salmon Oncorhynchus kisutch (Walbaum, 1792)	Asia, North America	6 lakes, Gulf of the Riga	Ex
III period	2012	Stocking	Regularly from 2013	Atlantic cturgeon Acipenser oxyrinchus (Mitchill,, 1815)[3]	North America	2 rivers of the Gulf of Riga	Un, captures of tagged specimens reported

1- Farmed in ponds, ornamental and game fish;
2- Farmed in recirculation systems;
3- Intentional and unintentional stocking, natural spread;
4- Species represented in regular catch (commercial, recreational);
5- Common, widespread species;
6- Stocked as hybrides