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THE LONG -TERM STOCKING OF FISH INTO LATVIA'S INLAND WATERS - SUCCESS OR FAILURE STORY?

Fish stock restoration is one of the main fisheries management measures, often used to increase or replenish stocks or compensate for their loss due to fishing, habitat degradation and/or other human activities that have transformed freshwater ecosystems. Fishery improvement is usually carried out using stock material raised in hatchery, but translocated wild fish can also be used. Stocking can also be unauthorized and/or accidental. Fish release (native or introduced species) is considered one of the oldest inland water management practices both in the world and in the territory of Latvia (Andrušaitis 1960; Welcomme 1992; Arlinghaus et al. 2002; Daupagne et al. 2021).
The results of the introduction of alien fish will not be discussed here; its results and ecological impacts on fish and fisheries in Latvia have already been published previously (Birzaks&Nitcis 2023).

Objectives and rationales of fish restocking
The restoration of native fish stocks and the introduction of non-native fish species is a relatively old practice in fisheries management. Fish stocking and translocation are considered to be one of the most effective resources management tools. As industrial society developed in the 19th century, the negative anthropogenic impact on the aquatic environment increased, creating the need to both develop aquaculture and improve fisheries management (Nielsen, 1999; Welcomme, 2001; Lavkey, 2005; Welcomme et al., 2014) The release of artificially reared fish, together with fishing regulation and habitat restoration measures, are the most important inland fisheries management tools aimed at protecting and maintaining fish resources at desired levels (Welcomme, 2001; Lorenzen et al., 2012; Arlingahus et al., 2016).
There are several types of restocking, depending on their purpose: 1) stock enhancement, in cases where the wild population is regularly supplemented with cultured fish, in water bodies with intensive fishing or degraded habitats; 2) rebuilding of depleted stocks by temporary releases of hatchery reared fish with aim achieve recovery effects more quickly as in natural system; 3) stock supplementation with cultured fish in very small and declining populations with aim to reduce the risk of extinction and maintain the genetic diversity, they serves conservation purposes; 4) reintroduction and translocation are intended to introduce farmed or captured native fish species with the aim of repopulating or establishing a native population in the receiving water body for the long term, 5) for cultured fisheries and/or ranching fish are released to maximize the fishery productivity of waterbody by creating a locally adapted population that will not reproduce; these waterbodies are exploited intensively and restocked frequently (Lorenzen, 2012; Lamothe et al. 2019).

Species stocked in Latvian inland waters
In total, 18 species of fish have been stocked and/or translocated in Latvian inland waters. They represented 40% of the Latvian freshwater fish fauna, which includes 42 fish and lamprey species (Aleksejevs & Birzaks, 2011): bream Abramis brama, eel Anguilla anguilla, Atlantic sturgeon Acipenser oxyrinchus, pike Esox lucius, roach Rutilus rutilus, rudd Scardinius erythrophthalmus, tench Tinca tinca, crucian carp Carassius carassius, ide Leuciscus idus, pike pearch Sander liucioperca, pearch Perca fluviatilis, burbot Lota lota, catfish Silurus glanis, whitefish Coregonus maraena, vendace Coregonus albula, salmon Salmo salar, trout/sea trout Salmo trutta un vimba Vimba vimba, grayling Thymallus thymallus, river lamprey Lampetra fluviatilis. Atlantic sturgeon are restored from their Canadian populations, in fact through introductions, but the Pan-European Action Plan for Sturgeons also foresees their recovery in the Baltic Sea basin (EC 2024).

Fish stocking in Latvia - historical overview and present data
The first fish farm in Latvia was established in 1885, and a system of state-owned fish farms was set up between 1929 and 1939. After World War II, fish restocking increased rapidly, driven by hydropower development in

Latvia, which included the construction of a HPS cascade on the region's largest river, the Daugava. Until 1974 the Daugava was transformed into a series of 3 reservoirs. HPS turbines operate during peak hours, altering the hydrological regime of the river with significant diurnal variations in water discharge. It has already been predicted that the runoff of nutrients and planktonic organisms into the Gulf of Riga will decrease significantly (Gaumiga, 1967), and that the composition of fish communities will change significantly both directly in the river and in the Gulf of Riga. The Daugava will completely lose spawning grounds for diadromous fish species, resulting in significant damage to fisheries (Pischula, 1950; Malikova, 1966; Peslak, Mitans, 1991; Ryapolova, Mitans, 1991).

To prevent and/or mitigate these losses, existing fish farms were reconstructed, and new ones were built. In total, 8 hatcheries operated in the four largest river basins in Latvia between the 1980s and 2000s, with the main objective of rearing juvenile diadromous fish for restocking. As a compensatory measure, HPS reservoirs restocking was also carried out by pike perch and bream, as well as introduced species. The planned number of juvenile releases was not achieved, but most of the state-owned hatcheries are still in operation.

The main scope of fish stocking is determined by the National Fish Stocking Plan (NFSP), which sets the number of fish to be released by species into publicly available rivers, lakes and reservoirs. The current plan will release about 19 million fish larvae and juveniles between 2025 and 2028, at a cost of around €2.3 million per year. The annual releases are expected to include 0.8 million salmon and sea trout smolts, 0.7 million one summer old vimba and pikeperch, 5 000 juvenile Atlantic sturgeon and 17 million river lamprey larvae and translocation and/or stocking 3 t of adult lamprey.

Glass eel restocking is carried out under the Latvian Eel Stock Management Plan (https://www.zm.gov.lv/lv/latvijas-nacionalais-zusu-krajumu-parvaldibas-plans-2009-2013gadam) and continued until 2019, with a total of 5.2 million glass eels released since. It should be noted that the restocking of this species is not intended to support any fisheries (EK) Nr. 1100/2007).

Some of the juvenile fish for restocking are bought from private fish farms. Municipalities can receive financial support from the State by submitting projects, for example, for pike stocking. Fish stocking has been carried out in an unauthorized way, both intentionally and unintentionally and/or accidentally.

Distribution, catches and abundance of stocked species

From the 1970s onwards, fish stocking increased in Latvia to compensate for losses to fisheries or to replenish and/or move fish species to water bodies where they were previously absent to create new stocks. Each year, 10-12 native species were released into Latvia's inland waters, declining to 6-8 species in recent years. Of these, salmon, sea trout, pike, river lamprey, vimba and pike perch have been released regularly for at least 30- 40 years.

Since the 1974, Latvia's most economically important salmon population (in the river Daugava), which accounted for about 90% of salmon catches, has been of hatchery origin, as river connectivity was lost. However, in the 1980-90s, the release of reared salmon smolts compensated for this loss, and salmon catches in coastal fisheries reached over 100 t/year in 1983-91, but declined several times, and have been only 10 t/year since 2003.

The largest landings of river lamprey were made between 1961 and 1977, before and shortly after the finalizing construction of the Daugava HPS cascade, reaching 400 t, most of which were taken in the river Gauja. From 1978 onwards, the lamprey catch declined several times, reaching a minimum of 8 t in 1980. From 1986 it increased again and stabilized at 100 t, but in the last decade it is back down to only 50 t per year, i.e. the lamprey catch in the Gauja has continued to decline. Before the loss of the Daugava connectivity, 90% of Latvia's river lamprey catches were made in the neighboring Gauja, but this has now dropped to 30%.

Sea trout is the most widespread diadromous fish species in Latvian rivers. It is found in all major rivers and their tributaries (except the Lielupe basin and its rivers), as well as in medium and small rivers and streams flowing into the Gulf of Riga and Baltic Sea Main Basin and has been recorded in 393 streams so far. Its regular introduction started in 1985, mainly in the rivers and streams at Daugava, Gauja, Salaca and Venta basins (27 watercourses in total). Its catches for the long period 1946-2003 were relatively stable at an average of 9 t/year, but despite stocking efforts, they declined from 2003 to an average of 6 t/year.

The vimba catches before river Daugava transformation were 56 t/year, they decreased significantly between 1979 and 1983 and averaged only 22 t. However, afterwards they stabilized and are around 69 t/year. It should be noted that part of its catch is taken in the Estonian part of the Gulf of Riga, where catches are approximately the same as in Latvia (Peslak, Mitans, 1991).

Non-migratory fish stocking activities in lakes and reservoirs peaked in the 1980s, when they were carried out in water bodies with a total area of 50-80 thousand ha/ year and have now declined to 30-50 thousand ha/year. However, total non-migratory fish catches have declined from 600 t in the 1950s-1980s to 260 t from the 1990s onwards. Reported angling catches have been stable, averaging 135 t/year since 2007, with angler surveys suggesting catches of around 1600 t/year (61% of the total catch in inland waters) (Birzaks 2007).

According to fishing, stocking and monitoring data, the distribution of some species in Latvian inland waters has changed because of stocking efforts. The distribution area of the pikeperch in Latvia has increased mainly because of translocation since the 1960s and has continued to increase (Aleksejevs, Birzaks, 2008). Data from introductions, fishing and monitoring showed that it also spread naturally, migrating along the rivers linking the lakes. Pikeperch catches have increased several times, reaching 30-40 t/year. Since the 1980s, they have been caught in 121 lakes and 4 reservoirs, as well as in major rivers. Stable naturally reproducing pikeperch

populations have existed for more than 10 years in 45 lakes and 4 reservoirs covering a total area of 43 and 10 thousand hectares respectively.
The distribution of catfish, originally found in the Daugava River, has also increased (Aleksejevs, Birzaks 2011). It is now also found in 11 lakes, some of which have established small self-reproducing populations. Monitoring data suggests that the species has also been introduced in an "unauthorized".
Pike are the most widely released fish species in Latvian inland waters. Its natural range is the whole country, and it can be found in 92% of standing waters - lakes and reservoirs. Since 1946, its catch has not changed significantly over time and amounts to 64 t per year. Pikes were released in 310 lakes, 32 reservoirs, covering 78 and 11 thousand hectares respectively, and 12 rivers. Since 2000, pike catches in angling have increased to 47 t, or 58% of the total. Efforts to supplement pike stocks have not increased pike catches.
The release of cultured whitefish, grayling and trout has proved ineffective, as no new self-sustaining populations have developed and/or the distribution of these species has not increased.

Pros and cons of fish stocking
Fish stocking is one of the main tools for managing inland fisheries, with the aim of improving the composition and quality of catches to obtain long-term economic and social benefits.
However, research results show that only a small proportion of stocking programs have had a tangible long-term expected effect (Cowx, 2004; Arlinghaus et al., 2015).
It can also have multiple negative impacts on native fish species. Cultured fish released into the wild differs from wild specimens in morphology, behavior, physiological, genetic and other characteristics. Those that are genetically based can accumulate in a population (Brown, Day, 2002; Lorenzen et al., 2012). The reproductive biology of cultured fish often differs from wild ones, especially in the case of salmonids, creating risks of interbreeding and loss of genetical integrity and diversity of population.
The precautionary principle should be considered in the planning and implementation of stocking. However, there are exceptions where fish stock restocking is the only option for recovery and/or conservation of fish stocks, e.g. to address the effects of anthropogenic alterations to the River Daugava. It is also necessary to create new benefits for fisheries and to introduce and exploit fisheries in small water bodies (Arlinghaus et al., 2003), to restore lost populations of protected fish species (so-called repatriation) (Lamothe, Drake, 2019), to rebuild fish communities after their extinction or accidental mass mortality (Bryson et al., 1975).
Success of stocking is mostly determined by size - dependent mortality of stocked fish (Cucherousset et al., 2007; Haugen et al., 2007). In the 1950s-1970s in Latvia, stocking was practiced by releasing fertilized eggs, larvae and salmon parr. In contrast, with improvements in hatchery technology from the 1980s onwards, juveniles for release are reared to at least one summer old (fingerlings), while salmon and sea trout are reared to 1- and 2-year-old smolts and condition. Only river lamprey is released at the larval stage.
However, there are few or no fishery results for the effectiveness of these improvements. At present, the river Daugava has an artificial salmon and sea trout populations, its salmon and sea trout populations survival depends on the cultured smolts release. In two other large Latvian rivers, the Gauja and the Venta, salmon and sea trout populations have been supplemented in the long term with artificially reared juvenile salmon. Their numbers substantially exceed than the natural salmon smolt production in these rivers. As the fin clipping results show, adult salmon and sea trout broodstock in the rivers Daugava, Gauja and Venta rivers in Latvia is currently mixed or farmed origin with share of cultured of salmon and sea trout adults accordingly 59- 99 % and 37- 100% (Medne et al., 2019).
During the rearing process (selection of broodstock, fertilization of eggs, incubation, long-term holding of juveniles in rearing facilities, etc.), selection may have been applied to the reared juveniles in generations, which has a corresponding effect on broodstock in long- term. In general, the artificial salmon smolt production in Latvian rivers has been many times higher than the wild salmon smolt production for a long time. In any case, catches of targeting artificially restocked salmon populations in Latvia declined over the years, suggesting that the post smolt survival of cultured smolts into the wild has declined significantly. Latvia's share of farmed salmon releases into the Baltic Sea is 16%, while its share of catches is only 1% of the total. This also confirms our hypothesis about the low efficiency of salmon releases in Latvia. The situation has not improved since the ban on salmon fishing in the southern Baltic Sea since 2022. Further stocking of farmed salmon and possibly sea trout in the Baltic Sea basin may be limited or considered limited and/or undesirable for the protection of their natural stocks (Palme et al., 2012).
Similarly, data from the river lamprey fishery show a long-term decline of catches. This change was also due to the increase in cod stocks in the Eastern Baltic. They reduced lamprey prey stocks (herring, smelt, sprat, and stickleback) and increased the natural mortality of lamprey during their marine lifetime (Birzaks et al., 2011). From 1986 lamprey stocks in Latvia increased again and catches stabilized at around 100 t/yr, but in the last decade it has been as low as 50 t/yr, however, in the river Gauja it continues to decline.
The construction of the Daugava HPP cascade disrupted the river's connectivity, while the operation changed the hydrological regime. Instead of natural seasonal fluctuations, the discharge of the river was replaced by drastic diurnal fluctuations, resulting in a decrease in the number of adult lampreys entering the neighboring river Gauja. Research has shown that homing in lampreys is not as pronounced and conservative as in other diadromous species, and that their entry into rivers is largely determined by the hydrological and meteorological conditions at the time (Ryapolova, 1970, Valtonen, 1980).
In the 1950-1960s, adult river lamprey tagging experiments showed that their mortality in the Gauja River

fishery was 50% of the spawning stock. Based on a simple adult- progeny relationship model, it was predicted that at least 40 t of adult lamprey (of this 20 t females) would be the optimal amount to ensure productive lamprey generations in the Gauja (Ryapolova, 1972).

In contrast, experiments with lampreys overwintering in a hatchery show that 100 hatchery females produce 660 000 self- burrowing larvae, compared to three times fewer during natural spawning (Ryapolova, Mitans, 1991). Accordingly, successful lamprey restocking in the Gauja River would require at least 7 to 10 times more self-burrowing larvae than is currently the case for the entire.

The catches of sea trout and vimba are stable, while heir catches are stable, while their harvest, which was strictly limited or even banned in the 1980s, has increased. This is an indication of their successful reproduction in neighboring rivers, which largely compensates for the loss of spawning and nursery areas in the rivers of the Daugava basin (Peslak, Mitans, 1991).

Pike, the most widespread fish species in lakes and reservoirs (92% of them), have been released into more than 300 lakes, rivers and reservoirs in Latvia. Pike fingerlings are released annually into water bodies where pike populations already exist. Scientific studies have mostly concluded that stocking pike fry or fingerlings as supplement native pike populations has only short-term effects and not population additive effects. Only the release of adult pike (> 25 cm) gives a higher yield compared to the release of smaller pike (fry or fingerlings), but this is also not long- term, pike population densities are decreasing to the level of ecosystem carrying capacity (Guillerault et al., 2018).

In Latvia, pike stocking is set as an annual action in the NFSP to supplement fish resources in publicly accessible water bodies. In Latvia, pike stocking is set as a regular action in the NFSP to supplement fish resources in publicly accessible (most of inland waters in Latvia) waterbodies. Pike stocking is a popular management measure at municipalities and anglers NGO's level. Scientific background of these programs implementation mostly contains only recommendation for number, size and season of juveniles to be released.

However, this is often driven by a "deeply rooted belief among stakeholders that stocking elevates stock size and catches"and it does; "it has become a ritualized habit" (Cowx, 1994; Arlinghaus, 2015; Guillerault et al., 2018). Release is often not determined by ecological or fishery considerations but by the availability of juveniles on the market. Juvenile pikes can usually be obtained by rearing them in polyculture in ponds with carp, their sale yields surplus income. Pike stocking material in Latvia is relatively readily available.

Scientific studies have in most cases concluded that stocking of pike fry or fingerlings where native pike populations exist has only short-term effects but no population additive effects. The usefulness of these measures for fisheries as such is also questioned (Westman et al., 1982; Daupagne et al., 2021). In contrast, stocking adult pike (>25 cm) gives an increase in harvest compared to smaller size (fry or fingerlings), but this is also not long lasting. However, pike population densities later decrease to a size determined by ecosystem capacity, increasing pike harvest for a short time (Guillerault et al., 2018). Vegetation is particularly important for pike in all life stages (Nilson et al., 2023), which largely determines the carrying capacity of a water body. In fact, this suggests that stocking has often been carried out without aim and without hope of success. Introducing pike into water bodies where the species is not present (quarries, small water bodies in put- and take fisheries, etc.) is often successful (Johnston et al., 2015).

The alternative of pike stocking is habitat restoration activities, provided availability of suitable habitat for all life stages (Engstedt et al., 2018).

The pikeperch is the only regularly released native species that has achieved the management target of establishing new stocks. Both its distribution and catches have increased. Since 1992, the species has been found in 54 lakes and 5 reservoirs but is caught and/or fished in 51 lakes (27 lakes in the 1950s). Most of their catches in Latvia are taken from lakes with artificial populations. In Latvian conditions, the suitable for pikeperch are about 100 eutrophic lakes with an area S> 70 ha and water transparency < 1 m, as well as potential spawning sites on hard-bottom substrates. Scare populations have also established in less eutrophic lakes. In hypertrophic lakes, where periodic low oxygen levels are observed, their stocking has failed (Aleksejevs, Birzaks, 2009; Aleksejevs, Birzaks, 2011).

Successful stocking pikeperch was driven by a number of factors, but mainly by increasing eutrophication of inland waters and climate change. There has been a northward shift in the distribution range of the pikeperch as a result of climate change (Westman et al., 1982; Karas, Sandström, 2002; Pecam- Hekin et al., 2011).

It should be noted that as an open water predator, the pikeperch exploits an ecological niche in the pelagic zone of lakes, where it has no food competitors and predators. It can affect fisheries by predating juveniles of other fish species perch, smelt, and vendace (protected species by 92/43 EEC), vector of fish diseases and parasites spread (Kangur et al., 2007; Kangur et al., 2020). In Latvia, the translocation of pikeperch has resulted in the establishment of pikeperch populations in four lakes (S=12.5 thousand ha) with natural populations of vendace representing 72% of their distribution area.

Both pike and pikeperch have been widely used (alone and together) in biomanipulations to improve water quality in lakes by reducing planktivorous fish stocks. However, the effectiveness of these stockings has rarely had the desired effect or has been obtained for a short period of time. It is more successful when carried out simultaneously with nutrient loads reduction and ameliorative removal of undesirable species (Lappalainen et al., 2013; Bennes et al., 2015).

Conclusions

Stocking within the NFSP, was created and performs tasks whose scientific rationale was already formulated

in the 1970s. The introduction of diadromous species has been stable over a period of 40 years, the quality of size at age related stocked fish has been improved. While, the stocking effect in fisheries is currently negligible or cannot be demonstrated using fishery data.
The effectiveness of introductions of native non-migratory species has also not been successful and the economic viability and potential negative impacts another fish stocks, protected species, etc. have not been assessed.
It is important to note that the Daugava, the largest river in Latvia, is blocked by the HPP cascade and restoring connectivity is not feasible in the near future. The potential of the other rivers (in terms of reproductive area and potential production of juveniles and smolts) can only partially compensate for the damage to fisheries.
In our view, the management of stocking needs to be improved, especially in terms of decision-making and overall strategy, as well as data collection (especially angling data), monitoring of results and scientific efforts.

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