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Review

LONG-TERM BALTIC SALMON *SALMO SALAR* (L.) RESTOCKING EXPERIENCE IN LATVIA

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Artificial propagation of salmonids in Latvia has a long-standing history, spanning nearly 140 years, periodically interrupted and resumed after the First and Second World War. Between 1939 and 1974, a cascade of three hydroelectric power plants was built on Latvia's most important salmon river, the Daugava, thereby preventing access to spawning areas. To maintain salmon stocks at an economically significant level, a scientifically based restocking programme of salmon stocks has been established and continues to this day. Over the years, salmonid rearing techniques developed, initially growing them to the larval stage, then to the juvenile stage, and finally to physiologically mature, saltwater-adapted smolts. The artificial propagation of salmon was not interrupted even during the collapse of the Soviet Union. To compensate for the loss of salmonid resources, the Institute of Food Safety, Animal Health, and Environment BIOR performs salmonid rearing, supplementing natural fish stocks with more than one million salmon and sea trout juveniles annually. The salmon stock in the Daugava River basin has been successively artificially maintained for more than fifty years, and the national restocking programme supports salmon stocks in the Gauja and Venta rivers with expectation of the wild stock stabilisation.

Keywords: *Salmon smolts, artificial stock maintenance, Daugava River.*

INTRODUCTION

Baltic salmon (*Salmo salar* L.) is an apex predator in the Baltic Sea. Salmon is one of the most valuable fish and the primary target species for one of the traditional professions in Baltic communities, fishing, since the Stone Age. According to Kulmala *et al*. (2012), Baltic salmon plays an important role in regulating food webs and maintaining the general ecological balance of ecosystems, and in addition, the estimated cultural services of salmon nowadays are more important as economic value of commercial landings.

Baltic salmon exhibit anadromous behaviour, meaning that they hatch in freshwaters, spend one to four years as juveniles in rivers until the smoltification process is complete, and then migrate to the sea, where they mature. Salmon has the longest migration routes over the Baltic Sea. After approximately two years at sea, they return to their native freshwater habitats to spawn. The Baltic salmon is a geographically isolated group of Atlantic salmon population (*Salmo salar* L.). Likely, North Atlantic salmon first migrated into the Baltic area about ten thousand years ago, when the glaciers melted and the Yoldia Sea formed (Lundqvist, 1965). Baltic salmon represent a genetically distinct group compared to their relatives in the Atlantic (Karlsson and Karlström, 1994). Ståhl (1987) compared salmon individuals taken from many rivers of the Baltic Region by gel electrophoresis of alleles of isozymes and confirmed differences even between different Baltic stocks. In several cases he found significant differences even between salmon taken from different parts of one and the same river. Later, the existence of different subpopulations was confirmed by other authors (Koljonen *et al*. 1999).

Currently, Baltic salmon naturally and regularly reproduce in less than 40 rivers, whereas in the past, the number of Baltic salmon rivers was considerably higher. Presently, the majority of the wild Baltic salmon populations originate from rivers of Sweden, Finland, Latvia, and Estonia (ICES, 2018; 2020).

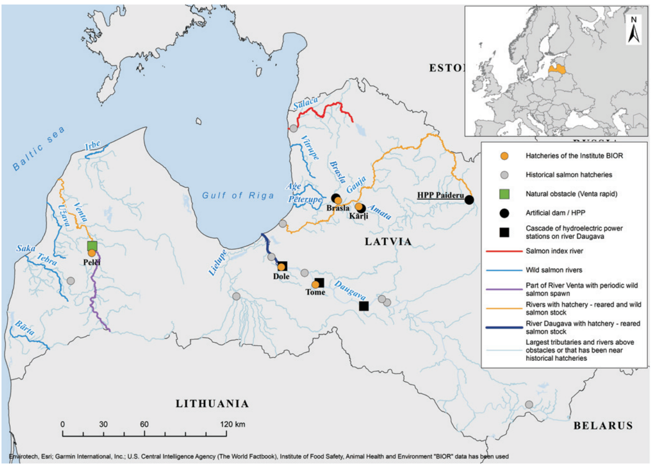

Fig. 1. Map of salmon rivers and location of salmon hatcheries in Latvia.

In Latvia, regular wild salmon spawning occurs in the rivers Salaca, Gauja, Aģe, Irbe, Venta, Saka, and Užava, as well as in Vitrupe and Pēterupe (ICES, 2020). Three of them discharge into the Gulf of Riga and four into the Main Basin of the Baltic Sea (Fig. 1). Today, 60% of the country's territory is estimated to be inaccessible to migratory fish species due to artificial obstacles (HELCOM, 2011) (Fig. 1).

To compensate for losses to migratory fish resources, the three main Latvian rivers Daugava, Gauja, and Venta, are annually stocked with hatchery-reared salmon smolts. Salmon populations in the Gauja and Venta rivers consist of a mixture of wild and reared fish, but the population of the Daugava River has a reared salmon stock. The broodstock fishery in Latvia is carried out in the coastal waters of the Gulf of Riga in October–November, as well as in the rivers Daugava, Venta, and Gauja. The annual smolt production in Latvian hatcheries varies according to the success of broodstock fisheries and annual peculiarities in the production process. In 2020, rivers of Latvia were stocked with 730,000 one year old smolts (1+), in 2021 with 561,000, in 2022 with 395 000, but in 2023 with 663,000 smolts age 1+ (ICES, 2023).

The potential motivation behind restocking and stock enhancement encompass several key factors: boosting the yield of commercial species; assisting the recovery of endangered species; promoting culture-based fisheries, primarily reliant on stocked fish for harvest; bolstering or complementing self-sustaining populations and moving towards restoration efforts in areas where natural stock expansion has been hindered by the degradation of spawning habitats or disruption of ecosystem connectivity.

This paper delves into the intricate history and present situation of salmon management in Latvia, providing insight into the biological and historical context underlying century-old developments. Study of the restocking from the late 19th century to present offers a comprehensive overview of the challenges, advancements, and achievements in Baltic salmon conservation. Through a detailed examination of historical records and scientific research, the paper sheds light on the role of hatcheries, rearing techniques, and strategies for sustaining salmon populations in Latvian rivers.

EARLY SALMON REARING DEVELOPMENTS

In Latvia, salmon egg incubation and fry release was initiated by aquaculture specialist Alvins Kiršs, who established the first private salmon and sea trout hatchery in Carnikava, by the Gauja River. The initial release of salmon fry into the Gauja occurred in 1885, followed by releases into the Daugava a few years later. Shallow, flow-through Atkins hatching apparatus were used for egg incubation. Unsatisfied with the propagation success, Kiršs transferred the hatchery to Vecsalaca village, situated by the Salaca River, in 1892. The following year, in 1893, 25,000 salmon fry were released into the Salaca for the first time.

In the following years, there was a notable increase in the number of artificially reared salmon fry that were successfully released: 35,000 in 1894, 1,220,000 in 1895, 1 million in 1896, and 1,673,000 in 1897. To increase the abundance of fish in the Daugava River, starting from 1898, the Rīga City Council and the Vidzeme branch of the Russian Imperial Society of Fishermen and Fish Farmers began purchasing salmon fry from A. Kiršs for annual releases in the Daugava. In 1898, the Riga City Council bought 125,000 salmon fry for releasing them in the Daugava and its tributaries – Ogre and Pērse. The transportation of live fry for a long distance was difficult in those times, because fish fry were transported in horse-drawn carriages and standard milk cans. To facilitate the transportation of fish fry from the Salaca to the Daugava, a small salmon hatchery initially was established in Rīteri Manor specifically for the Daugava River's needs in the spring of 1898, overcoming difficulties with fish fry transfer. In the following years, larval releases continued in the Salaca and Daugava rivers. In 1909, A. Kiršs continued to rear salmon fry in the Vecsalaca hatchery and in its branch Berkaviņa, located along the Daugava River upstream from Ikšķile town. In 1902, a salmon hatchery was established in Jelgava, located in the Lielupe River basin. It operated until 1911 when it was closed due to the difficulties of obtaining salmon breeders from the Lielupe for spawning (Eglītis, 1939 a).

All mentioned salmon fry were obtained only from spawners caught in the Daugava, Salaca, and Lielupe river basins. An exception occurred in 1905, when with special permission, an additional 50,000 fries were obtained from hatchery on Luga River, located in Russia. In 1902, salmon fry were not released from any hatchery, because all collected eggs died during incubation (Eglītis, 1939 a).

The breeding of fish fry continued until 1916 when it was interrupted by the First World War (Andrušaitis, 1960). Altogether, from 1893 to 1916, a total of 368,000 salmon fry were released in the Lielupe River, 2,617,000 in the Daugava River, and 6,308,000 in the Salaca River (Eglītis, 1939 a). Fry releases in different river basins are reflected in Figure 2.

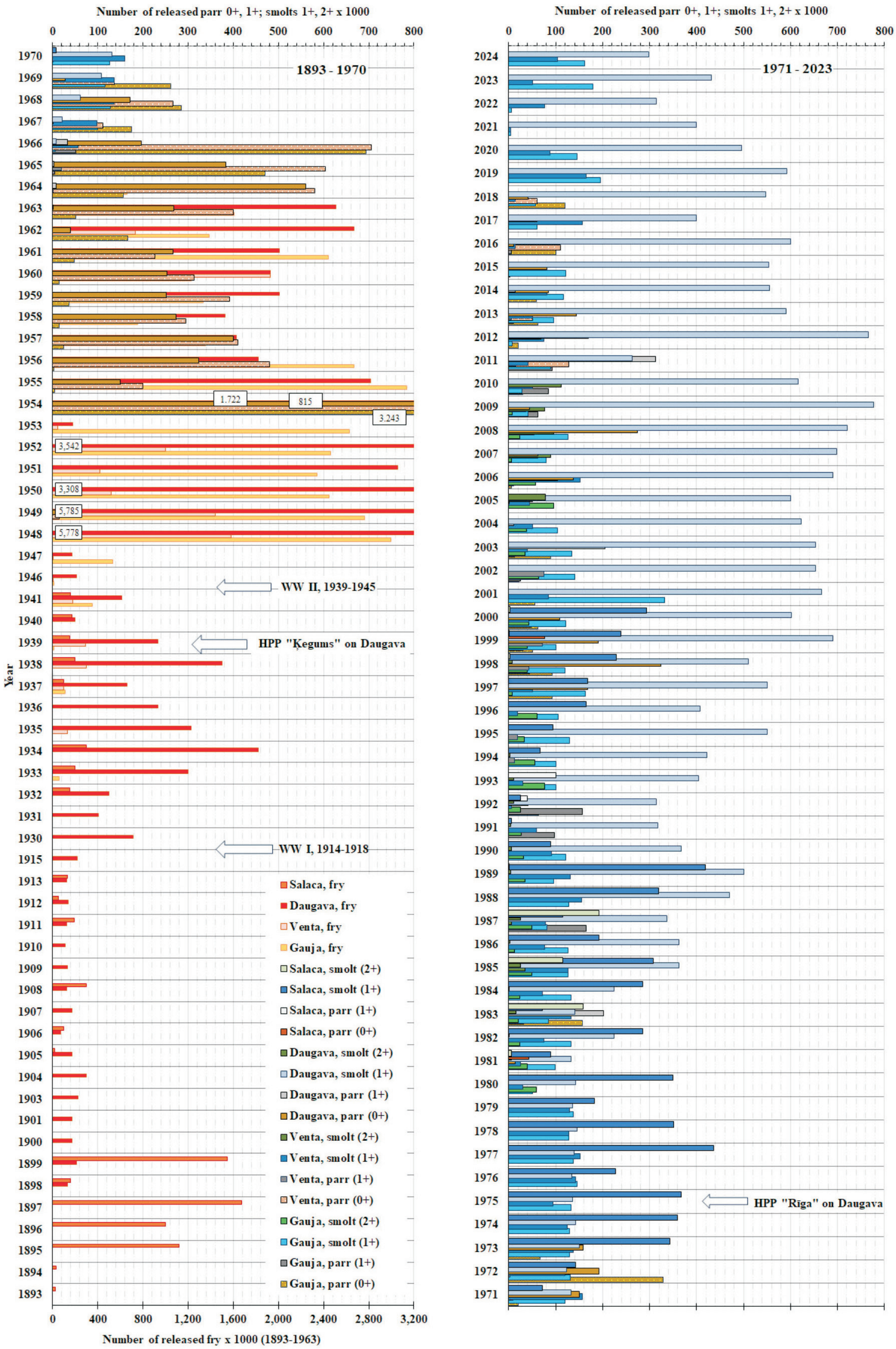

Fig. 2. The amount of released salmon in stages fry, fingerling 0+, parr 1+, smolt 1+ and smolt 2+ in rivers Daugava, Gauja, Venta, and Salaca, from 1893 to 2024.

CONTINUATION OF FRY RESTOCKING DURING LATVIA'S FIRST PERIOD OF INDEPENDENCE

After the end of the First World War, fish fry rearing was re-established, however for the period from 1920s to 1930s, there is limited information available on artificial fish propagation in Latvia. Only a few articles on fish breeding and fisheries were published in periodicals such as *Zvejniecības Mēnešraksts*, *Zemkopis*, *Jaunā nedēļa*, and others.

In 1922, the salmon hatchery "Salaca" situated by the Salaca River was partly renovated, and fish reproduction efforts continued. Later, this hatchery was completely renovated and operated until 1930. In 1923, a total of 219,000 salmon fry were released in the Salaca (Fig. 2).

In 1923, the hatchery "Koknese" was established. Flow-through Atkins hatching apparatus were installed there for the incubation of 4–6 million salmon eggs. Support hatcheries for the "Koknese" were also established in Ķegums and Ikšķile. In each of these hatcheries, the Grimm hatching apparatus were installed for incubation of 2 million eggs. The hatchery "Koknese" released 75,000 salmon fry into the Daugava in 1924, and 340,000 salmon fry in 1925.

To reproduce Daugava River fish stocks in Latgale, another hatchery was established in Krāslava in 1924, which operated for only six years — it was closed in 1930 (Andrušaitis, 1960).

During the period between 1923 to 1927, altogether four fish hatcheries operated in Latvia: the Latvian Fish Farming Promotion Society's Hatchery Salaca, the Latvian Agronomist's Hatchery in Burtnieku Manor, the Latvian Fisheries Hatchery in Koknese, and the trout hatchery at Kazdanga Fish Farming School in Kazdanga Manor at Aizpute (Andrušaitis, 1960; Anonymous, 1927 a). From them, three hatcheries contributed to the salmon restocking efforts in Latvia. In the period from 1923 to 1930 the fish hatchery "Salaca" released 1,080,000 salmon fry in Salaca River, the fish hatchery "Koknese" released 780,000 salmon fry into rivers within Daugava basin, and the fish hatchery "Krāslava", also located along the Daugava River — 215,000 salmon fry.

In 1926, the fish hatchery "Koknese" slightly expanded, as fish incubation was improved by the installation of Weiss breeding jars. However, the hatchery "Koknese" operated only until 1929, because in 1927, the government of the Republic of Latvia allocated the state budget for the construction of a one new central state fish hatchery situated by the Daugava River near Ķegums.

In the 1930s, the main salmon broodstock fishery for artificial propagation needs was conducted in the Daugava River at Dole Island, which generally accounted for 2/3 of all salmon breeders caught. Periodic difficulties in collecting salmon broodstock were reported in the newspapers of that time, often due to unfavourable weather conditions. For instance, in 1925, only 1/3 of the expected catch was achieved, because the water level in Daugava rose so high that the fishing gears were in danger of being damaged and had to be removed from the river. Fishing in other Daugava river locations, Ķegums, Koknese, and Pļaviņas also faced challenges. Salmon broodstock fishing in that year lasted only from October 23 until November 6. As a result, 75 salmon spawners were caught and 240,000–750,000 eggs were obtained. By January 1926, 230,000–250,000 eggs were successfully incubated, from which 40,000 salmon fry were released in the spring of 1926 (Anonymous, 1926).

Unfavourable weather conditions persisted during the autumn of 1926, making salmon fishing extremely unprofitable. Only a few male and female salmon were caught in the Daugava during spawning, resulting in only 10,000–16,000 eggs, which were not profitable for incubation in the hatchery until spring (Anonymous, 1927 b).

It is important to note that during the 1930s, the fish hatchery "Salaca" exported a considerable quantity of salmon eggs over far and long distances, reaching destinations even more than thousands of kilometres away from Latvia. Altogether 1,714,000 eggs were exported to France and Holland (Eglītis, 1939 b). It is essential to consider that transportation options, road conditions, and technical support during that era were quite challenging. Fish eggs and fry were typically transported using railway or horse carriages, often in metal milk cans with open lids to ensure adequate air circulation. The change of fresh water was performed from open water sources wherever possible on the way from the fish hatchery to the release site, with taking care not to keep cans warm. In cases where the cans became too warm, they were cooled by dropping ice in the cans (Grigulis, 1930).

ESTABLISHMENT OF THE FISH HATCHERY TOME — MEASURE TO COMPENSATE DAUGAVA RIVER DAMMING IMPACT ON MIGRATORY FISH RESOURCES

In the 1930s, Latvia embarked on a plan of national importance focused on the country's electrification, necessitating the reorganisation of the fragmented network of existing hatcheries into one centralised facility, the Tome fish hatchery (FH). The location site of the FH Tome was carefully selected by the Daugava River near Ķegums, at the site where the national hydroelectric power plant (HPP) and water reservoir would be constructed. It was planned that the water reservoir would serve as a self-draining water source for the hatchery. The first FH "Tome" of the Republic of Latvia began its operation in 1929 equipped with the Atkins hatching apparatus for salmon and sea trout incubation and Weiss apparatus for white fish.

With FH centralisation, the state had far-reaching national goals aimed to compensate for anticipated loss for migratory fish resources once the Daugava River damming would be completed, resulting in the loss of salmonid spawning areas. This centralised approach aimed to compensate the potential adverse impacts of hydro-electrification development on Daugava migratory fish population loss and contribute to the conservation and artificial management of Latvia's fish resources.

The HPP "Ķegums" started operation with electricity production on 5 August 1936. As a result of the construction of the HPP, approximately 13 km² of land was flooded and the salmon population lost access to its natural spawning grounds in the upper reaches of the Daugava, including its main tributary the Aiviekste. As a compensatory measure for the salmon population spawning territory loss, the salmon fry rearing successively proceeded in the FH "Tome", followed by the release of fingerlings into the Daugava. In 1938, FH "Tome" was managed by experienced manager A. Zandbergs, who had experience as a fish farmer for more than 15 years. A. Zandbergs learned his profession in Russia, where he worked as an instructor in one of the largest Russian fish farms in Kamchatka (Grigulis, 1930).

The second FH "Kārļi" was established in 1932, for rearing and restocking of the Baltic salmon and sea trout fry for the Gauja River basin. The restocking was necessary, due to the prospectively planned construction of a next state HPP on the Amata River. Similarly, as FH "Tome", also FH "Kārļi" was located downstream of the HPP dam by the Amata. For the breeding of salmon eggs "Tome" used natural flow-through river water from the Daugava and Līčupīte, a tributary of the Daugava, while FH "Kārļi" used Amata River water, supplied directly from HPP reservoir, as the self-drain system.

The third national fish hatchery was established in 1937, in Pelči, situated in the Kurzeme region near the Venta River and Kuldīga city, where the waterfall Ventas Rumba is located. Ventas Rumba serves as a natural barrier to fish migration, preventing salmon spawners from crossing upstream during autumn when water levels are low.

In all three hatcheries, "Tome", "Kārļi", and "Pelči", salmon eggs and fry were incubated using water from the same river basin where they were released later, while FH "Kārļi" incubated fry also for the Salaca River. Together, these three state hatcheries released approximately 3 million fry annually (Mitans, 1975). Altogether in the period between 1930s and 1940s, a total of 13,665,000 salmon fry were released into the river basins of the Daugava, Gauja, Salaca, and Venta.

During the following years, due to the Second World War, the operation of the hatcheries was partially halted, and they suffered significant material losses (Andrušaitis, 1960).

DEVELOPMENT OF SALMON REARING TILL FIRST YEAR FINGERLINGS

After the Second World War, Latvian hatcheries resumed salmonid restocking. By the late 1940s, three hatcheries released fry into the main salmon rivers. FH Tome stocked the Daugava River and its tributaries Ogre, Līčupe, Ķekava, Tome, Kausupīte, and others, FH Pelči worked in the Venta River, including its tributaries Venta, Ēda, Riežupe, Veldze, and others, and FH Kārļi worked in the Salaca and Gauja River basins – Amata, Kumada, Skaļupe, Pērļupe, Rauna, Rakšupe, Jaunupe, and other rivers (Andrušaitis, 1960).

Researchers emphasised that juvenile salmon survival in the wild improves when fish are released at larger, healthier stages. Therefore, hatcheries under the Latvian Fisheries and Aquaculture Administration (LATRYBVOD) initiated experiments on rearing more mature salmon. Nurseries were equipped with Atkins, Viljamson, or Orava hatching apparatus. For continuous rearing, ponds were built in FH Tome and Pelči. From 1947 onward, part of the salmon and sea trout fry underwent extended rearing in ponds and tanks for 30–40 days, fed with oligochaetes, spleen, fish-processing waste, and cottage cheese. Early trials showed that rearing time was less decisive than appropriate feed supply, emphasising the necessity for more suitable artificial diets. The Latvian branch of All Union Research Institute of Marine Fisheries and Oceanography (VNIRO) began research aimed to extend the rearing period (Pischula, 1950).

According to LATRYBVOD annual reports, the three hatcheries released 2.0 million salmon fry (30–40 days old) in 1947, 10.1 million in 1948, and 10.0 million in 1949.

Between 1950–1951, All-Union Research Institute of Lake and River Fisheries (VNIORKH) tested rearing in FH Pelči ponds, experimenting with fry age, stocking densities, fertilisation, artificial feed (minced fish, oligochaetes, spleen), and light to attract insects. Studies monitored growth, physiology, and oxygen regimes. Recommendations were developed for salmon egg incubation, pond preparation, stocking, fertilisation, and drainage, providing the first standardised guidelines (Ioffe *et al.*, 1955). Thanks to these efforts, in some years, releases exceeded 12 million salmon fry and fingerlings.

In the 1960s, the Baltic Fisheries Research Institute (BaltNIIRKH) advanced hatchery productivity. A breakthrough came in 1962 with the introduction of the KRT feed paste (Malikova, *et al.*, 1969), composed of blood and fish powder, silkworm pupae, algae, mustard, chalk, yeast, fish oil, vitamins, antibiotics, and trace elements. Initially the moist paste was difficult to handle, but nevertheless, in the first year of moist KRT use, fingerling production increased more than eightfold. This led to a gradual phase-out of immature fry releases, while production of viable fingerlings increased to nearly 1 million by 1965. That same year, hatcheries officially adopted KRT for juvenile salmon rearing (Malikova *et al.*, 1984).

By 1963, hatcheries had already initiated rearing to the smolt stage, achieving average final weights of 12–21 g. This advancement led to a 90-fold increase in smolt releases by 1967 (Fig. 2). The use of moist KRT accelerated growth, improved juvenile quality, enhanced return rates, and ultimately increased fishery yields (Hasina, 1978).

To scale up smolt production, fry rearing was shifted from open ponds to high-density indoor tanks. Under the leadership of Prof. Elena Malikova, research focused on feeding protocols, growth, and physiological indicators (Malikova, 1966; 1967). This laid the foundation for intensive hatchery production.

The need to improve restocking efficiency was driven by the planned damming of the Daugava River, Latvia's main salmon river, through construction of the Rīga HPP, located 35 km from its mouth (Malikova *et al*., 1978). Completion of the full cascade of three hydropower plants blocked salmon migration, eliminating access to natural spawning and juvenile habitats. Preservation of Daugava salmon stocks and fisheries required a complete shift to hatchery-based reproduction. This was a matter of national importance, as mark–recapture studies showed that Daugava salmon previously accounted for 75–80% of fishermen catches.

A LEAP IN SALMON REARING TO SMOLT STAGE OWING TO THE INVENTION OF GRANULATED FEED

Until the 1970s, hatcheries released mainly salmon fry, smaller numbers of first-year parr, and very small amounts of smolts physiologically prepared for downstream migration. Parr were reared primarily in open ponds with natural feed at densities of 3–5 fish/m². Early attempts to expand artificial salmon production were largely ineffective, as only a small proportion of juveniles could be reared on moist artificial feed; parr weights rarely exceeded 0.8–1.0 g, and production losses often reached 60–70%. Commercial returns from fry releases were negligible due to high river mortality. While fingerlings performed slightly better, returns from 1 g parr remained low at 1–3% (Malikova *et al*., 1969).

To improve and scale up production, hatcheries transitioned from moist paste diets to buoyant dry pellets. Research on pellet composition initiated BaltNIIRKH in 1973, leading to the development of several formulations and refinement of rearing biotechnology. Industrial-scale pellet manufacture was carried out at the fishermen's collective farm Banga.

Implementation of pelleted feeds enabled large-scale rearing of Baltic salmon to the smolt stage, a critical phase adapted for seawater life, with releases reaching 735.4 thousand smolts in 1975. Four state hatcheries (Tome, Pelči, Kārļi, Salaca) shifted to producing one-year-old (1+) parr and smolts, as well as two-year-old (2+) smolts. Average weights ranged from 10–20 g for 1+ parr and smolts, and 75–100 g for 2+ smolts. Releases occurred from late April to late June, with the majority in early June at the mouths of the Daugava, Gauja, Venta, and Salaca rivers. Estimated returns from 1,000 released 2+ smolts for the coastal fishery were 3.5–4.0%, equivalent to 280–360 kg (Mitans and Reznikova, 1980).

Improvements in salmon rearing were implemented just before and during the final damming of the Daugava (Hasina, 1978). With the completion of the Rīga HPP in 1974, Latvia's main salmon river lost its migration routes and breeding grounds: the extensive spawning areas around Dole Island were destroyed, and upstream habitats were flooded and cut off by dams. These losses were mitigated through joint efforts of scientists and state hatcheries, whose advances in juvenile rearing helped sustain Baltic salmon populations and the fisheries sector. To further compensate for resource losses caused by the Rīga HPP, the Dole hatchery was established in 1986.

As artificial rearing efficiency improved, the necessity to safeguard wild salmon resources became evident. A pivotal proposal called for maintaining natural spawning habitats in wild salmon rivers, leading to the recommendation to establish a biosphere reserve in the Salaca River basin (Malikova, 1966). This vision materialised in the 1990s with the creation of the Northern Vidzeme Biosphere Reserve, formalised by the Council of Ministers' decision "On the Creation of the Northern Vidzeme Regional Nature Protection Complex and Measures for the Organisation of a Biosphere Reserve". The reserve encompassed the Salaca and its catchment, recognised as the most important salmon spawning area on the eastern Baltic Sea coast.

BALTIC SALMON POPULATION AND RESTOCKING EFFECTIVENESS RESEARCH LED BY ANDIS MITĀNS

With the establishment of salmon smolt production in a large-scale, new questions arose on smoltification in the wild, characterisation of "wild" downstream migrants, migration timing, and commercial return. Timing was critical, as hatchery smolts achieved the highest returns when releases coincided with wild migration (Lindroth, 1965; Mitāns, 1967).

Under the leadership of *Dr. biol*. A. Mitāns, extensive studies were conducted on both wild and hatchery salmon juveniles, with particular focus on the Salaca. Downstream migration in the Salaca was monitored with a counting trap at the river mouth. Results showed that migration begins after spring floods in late April or early May, when water reaches 6–7 °C. Mass migration starts at ~9 °C and peaks after rainfall, when temperatures exceed 12 °C. Optimal conditions included high water level, strong flow, increased turbidity, and overcast skies. Smolts migrated mainly at night, in small groups, although daytime migration occurred during peak periods. The mass migration phase lasted ~20 days in May, with a 1–3 day peak usually in the second or third week. The full migration period extended up to 1.5 months. These findings guided the adjustment of hatchery release schedules to coincide with natural migration (Mitans, 1972; 1975).

Feeding ecology was also investigated. Stomach analysis showed Baltic salmon parr are strict stenophages, relying almost exclusively on amphibiotic insect larvae. Food supply strongly influenced growth, smolt production, and overall productivity (Mitāns, 1972; 1975).

The determination of the smoltification age was a key milestone, revealing distinct growth and migration patterns. Fast-growing individuals migrated as one-year-old smolts (1+), while the majority completed smoltification at age two years (2+). A smaller proportion migrated at age three years (3+), and some became precocious males maturing in freshwater. In Salaca (1964–1972), 24% migrated at 1+, 73% at 2+, 3% at 3+, and 0.1% at 4+. One-year smolts averaged 11 cm/14 g, two-year-olds 13 cm/25 g, and three-year-olds 15 cm/32 g. These migration data helped to adjust release smolt age and time to wild migration (Mitans, 1975).

Survival of released fish is size-dependent. From released fry of 2–3 g, only 1% reach smolt stage; from 7 g parr, 4%; from 13 g parr, 36%. Two-year juveniles with an average weight of 22-24 g were almost all smoltified salmons, ready for release and migration (Mitans, 1975). The natural survival rate and return after restocking in different stages are summarised in Table 1.

In the 1970s, commercial return from 100 wild smolts was estimated at ~8 adults (70 kg), while 100 hatchery-reared smolts yielded ~4 adults (36 kg). However, survival during early development was far higher in hatcheries: from 1,000,000 eggs, hatcheries produced ~125,000 smolts (1+) and 5,000 adults, compared to 15,000 smolts and 1,200 adults from the same number of wild eggs. Thus, overall commercial return from hatchery fish was four times greater, with a calculated return of 0.50% from artificially reared eggs versus 0.12% from natural spawn (Mitāns, 1975; Table 1).

To further improve efficiency, it was considered essential that most hatchery smolts reach 14–16 g at release to ensure successful downstream migration (Mitāns, 1975).

Between 1976 and 1979, hatchery-reared salmon comprised 41–65% of coastal catches, as determined from adipose-fin–clipped fish (Mitāns and Kazanskaya, 1982).

Altogether, Mitāns' long-term studies provided a foundation for synchronising hatchery practices with natural processes, optimising smolt size and age at release, and quantifying the comparative efficiency of artificial salmon reproduction versus natural.

MAINTENANCE OF SALMON RESOURCES AND RESTOCKING WITHIN THE ARTIFICIAL FISH RESOURCES REPRODUCTION PROGRAMME OF LATVIA, 1989 TO PRESENT

From 1989 to 1997, salmon restocking followed an annual release plan prepared by the Latvian Fisheries Research Institute (LFRI) and implemented by FH: Tome, Kārļi, Brasla, Dole, Pelči, Salaca, and Ķegums.

Table 1. Reproduction efficiency of wild and artificially reared Baltic salmon (1960–1972), depending on the peculiarities of the freshwater period (Mitans, 1975).

Salmon stage	Artificially reared, amount	Artificially reared, survival, %	Natural, amount	Natural, survival, %
Eggs	1,000,000	-	1,000,000	-
Fry 0+	590,000	59	50,000	5
One year old parr, 1+	490,000	83	25,000	50
Smolts, 1+	125,000	26	15,000	60
Return	5000	4	1200	8

In 1997, the International Baltic Sea Fisheries Commission adopted the Salmon Action Plan 1997–2010, which established a specific target for the Salaca River: the creation of a self-sustaining salmon population by 2010. Consequently, hatchery releases into the Salaca were discontinued in 2000 to promote the recovery of the wild stock.

By 2008, the Salaca met the criteria defined by the ICES Assessment Working Group on Baltic Salmon and Trout (WGBAST) for classification as a wild salmon river (ICES, 2008). With hatchery releases halted and more than 90% of smolt production originating from natural reproduction, the salmon population became self-sustaining. Since 2010, following two generations of natural spawning without stocking, the Salaca has been recognised as a fully wild salmon river where parr densities have shown an increasing trend since 2010. Although smolt production between 2017 and 2022 remained below 50% of the Potential Smolt Production Capacity (PSPC), it rose to 64% in 2023 (ICES, 2024).

In November 2004, the LFRI was restructured into the state agency Latvian Fish Resources Agency (LFRA), which incorporated the institute and seven state hatcheries ("Brasla", "Dole", "Kārļi", "Ķegums", "Pelči", and "Tome"). Since 2010, the Institute of Food Safety, Animal Health and Environment BIOR has been responsible for restocking public water bodies under the National Fish Resources Restocking Programme. This programme, revised every four years, is based on scientific assessment of fish resources and addresses the need for restocking, enhancement of valuable stocks, and compensation for losses due to economic activity, fisheries, and angling (Treigute and Mitāns, 2001; Bārtule, 2021). Its primary objectives are to maintain natural fish stocks in a sustainable condition, preserve homing and adaptive traits of salmonids, and tailor management to the ecological characteristics of each river basin.

The Daugava River population is restocked continuously, as migration routes to spawning grounds are blocked by hydroelectric power plant (HPP) cascades (Fig. 1). Populations in the Gauja and Venta rivers are also restocked, as large sections of these rivers contain degraded spawning and nursery habitats, resulting in low natural production (ICES, 2023).

Broodstock fisheries are conducted in natal rivers each autumn, with eggs incubated in hatcheries and juveniles reared in flow-through systems in river water. Smolts are released in spring, but numbers vary depending on broodstock availability. Recent research showed that natural immunostimulants such as beta-glucans and probiotics improve health, immunity, and survival during critical autumn–winter periods (Medne and Savicka, 2003; Revina *et al.*, 2020; 2023; Purviņa *et al.*, 2025).

Historically, juveniles were released at multiple stages (fry, fingerling, parr 1+, smolts 1+ and 2+) (Fig. 2). Until 2010, many were released as mature 2+ smolts (~80 g), but for economic reasons releases shifted to younger stages. Since 2019, only smolt stages are stocked, all marked by adipose fin clipping. Current annual releases average 0.65 ± 0.17 million smolts (1+). Their mean weight varies by river: 18 g in the Gauja, 20 g in the Venta, and 25 g in the Daugava. Releases take place in spring, once river water reaches 8 °C (Purviņa *et al.*, 2019) according to the Artificial Fish Reproduction Plan for 2025–2028.

Assessment of returning spawners shows most salmon spend 2–3 years at sea. The basic assessment of salmon spawner age upon return assumes that after smolt migration to the sea, most salmon spend at least two to three years in the sea. Broodstock catches in 2019–2024 indicate that hatchery fish dominate the Daugava (100%) and represent variable shares in the Venta (20–72%) and the Gauja (0–70%) (Table 2) (Anonymous, 2024).

Broodstock results confirm that Latvian salmon stocks in the Daugava are entirely artificial, while in the Gauja and Venta, the share of hatchery fish remains significant. Weak spawner returns in 2023 reflected dry summers and poor 0+ parr densities. In contrast, coastal and open-sea fisheries are dominated by wild fish, due to mixing of stocks during feeding migrations (Anonymous, 2024).

Licensed catch-and-release angling for kelts in the Gauja also indicate a notable, though lower, contribution of hatchery-origin fish, and it should be noted that this reflects only fish that survive after spawning (Table 3).

Thus, while hatcheries dominate spawner supply in regulated and degraded rivers, wild salmon still prevail in marine catches, underscoring the importance of both artificial propagation and habitat protection. The Restocking Programme remains central to maintaining Latvia's salmon resources, balancing the need for hatchery support with conservation of wild populations.

Table 2. The share of fin-clipped (hatchery reared) salmon in broodstock fisheries among reported breeders with adipose-fin status (2019–2024, Anonymous 2021; 2022; 2023; 2024).

	Adipose fin-clipped salmon, %		
Year	Daugava River	Venta River	Gauja River
2019	100.0 (n = 258)	72.0 (n = 25)	69.6 (n = 46)
2020	100.0 (n = 88)	68.1 (n = 47)	54.5 (n = 11)
2021	100.0 (n = 164)	67.9 (n = 28)	24.1 (n = 54)
2022	100.0 (n = 241)	58.1 (n = 31)	46.1 (n = 102)
2023	100.0 (n = 48)	20 (n = 5)	0 (n = 1)*
2024	100.0 (n = 166)	43.2 (n = 37)	36.7 (n = 56)*

* Including the Brasla River, a tributary of the Gauja.

Table 3. The share of fin-clipped (hatchery reared) salmon in fisheries and in licensed angling landings (Anonymous 2021; 2022; 2023; 2024)

Adipose fin-clipped salmon, %			
Year	Coastal fisheries	Open sea fisheries	Licensed angling for kelts in the Gauja River
2019	15.4 (n = 39)	23.1 (n = 13)	-
2020	25.6 (n = 82)	26.1 (n = 241)	-
2021	9.1 (n = 33)	16.8 (n = 179)	10.9 (n = 138)
2022	5.7 (n = 53)	26.3 (n = 209)*	35.1 (n = 41)
2023	6.9 (n = 58)	44.8 (n = 58)*	28.6 (n = 35)
2024	15.9 (n = 44)	20.9 (n = 110)*	0

* trolling (recreational fisheries) and scientific data collection using longlines (annual samples up to 200 specimens)

The Daugava population represents the most striking case: since the construction of the Rīga HPP in 1974, natural reproduction has been impossible, and the stock has survived exclusively through artificial propagation. In contrast, the Salaca River demonstrates that, where habitats remain intact and hatchery input is withdrawn, wild salmon populations can recover. Its status as a "wild salmon river" confirms that natural reproduction is viable if ecological conditions are protected. The Gauja and Venta rivers illustrate the intermediate case: natural reproduction persists but remains supplemented by hatchery support due to habitat fragmentation and degradation.

Research by Latvian scientists, notably Andis Mitāns, demonstrated how migration timing, smoltification age, and release size assessment strongly influence survival and returns. His findings underpin current strategies: releasing older, larger smolts synchronised with natural migration, ensures higher survival. Hatchery innovations — from KRT paste to pelleted feed — enabled the transition from fry to smolt production, substantially improving efficiency and fisheries returns.

CONCLUSIONS

Over more than 140 years, Latvia has accumulated unique experience in salmon propagation, moving from small-scale fry releases in the late 19th century to modern hatchery programmes that today underpin salmon management in the Baltic. This long-term continuity reflects both the importance of salmon to national fisheries and the adaptability of institutions and scientists in development of methods of artificial rearing, feeding, and stock management.

Since 1989, national restocking programmes, updated every four years, have structured artificial propagation. Implemented by institute BIOR, they integrate broodstock fisheries, incubation, rearing, and release across river basins, while adapting to local ecological realities. The programme aims not only to sustain catches but also to preserve homing ability and genetic resources. Research on immunostimulants and health management further enhances hatchery output (Medne and Savicka, 2003; Revina *et al.*, 2020; 2023).

Despite advances, challenges remain. Climate change has already altered seasonal water regimes, with periodic hot summers, reduced runoff, and increased disease pressure. Habitat loss from hydropower continues to constrain production, and predation and marine mortality further limit returns. In regulated rivers like the Daugava, hatcheries will remain indispensable. Yet the persistence of wild stocks in Salaca and partial natural reproduction in Gauja and Venta underline the importance of habitat protection and river restoration.

The broader Baltic context is equally important, as across the basin, hatchery fish now outnumber wild ones. This imbalance raises concerns about genetic diversity, adaptation, and long-term resilience. Effective conservation must therefore combine hatchery support with strict protection of natural spawning grounds, dam removal where possible, and restoration of river connectivity.

In summary, Latvia's salmon management stand on three pillars: (1) hatchery-based reproduction, essential in regulated and degraded systems; (2) habitat conservation and restoration, vital for sustaining wild populations; and (3) adaptive policies and research, ensuring restocking remains effective under changing ecological conditions.

Thus, while hatchery-reared salmons dominate spawner supply in regulated rivers and wild salmon still prevail in marine catches, highlighting the importance of both artificial propagation and natural reproduction, ensuring a sustainable future for Baltic salmon requires integrating hatchery practices with habitat protection and international cooperation, to safeguard both fisheries and biodiversity for generations to come.

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ILGLAICĪGA BALTIJAS LAŠA (*SALMO SALAR*) KRĀJUMU ATRAŽOŠANAS PIEREDZE LATVIJĀ

Mākslīgai lašveidīgo zivju atražošanai Latvijā ir ilgstoša, gandrīz 140 gadu, pieredze, kas periodiski tikusi pārtraukta un atjaunota, gan pēc Pirmā, gan Otrā pasaules kara. Laikā no 1939. līdz 1974. gadam uz Latvijas nozīmīgākās lašupes — Daugavas, tika uzbūvēta trīs hidroelektrostaciju (HES) kaskāde, kas pārtrauca dabisko lašu migrāciju un piekļuvi to nārsta teritorijām. Lai saglabātu lašveidīgo krājumu zivsaimnieciski nozīmīgā stāvoklī, ir izveidota zinātniski pamatota lašu krājuma atražošana, kas tiek turpināta līdz šai dienai. Gadu gaitā notikusi lašveidīgo audzēšanas attīstība, sākotnēji līdz kāpura stadijai, tad līdz mazulim un visbeidzot — līdz fizioloģiski nobriedušam, sālsūdens dzīvei adaptētam smoltam. Lašu mākslīgā pavairošana turpinājās arī sociāli politisko pārmaiņu laikā, tostarp Padomju Savienības sabrukuma laikā. Lai kompensētu lašveidīgo resursiem nodarīto zaudējumus, Pārtikas drošības, dzīvnieku veselības un vides zinātniskais institūts BIOR īsteno lašveidīgo audzēšanu, ik gadu papildinot dabiskās populācijas ar vairāk nekā vienu miljonu lašu un taimiņu mazuļu. Daugavas upes baseinā lašu krājumi tiek veiksmīgi mākslīgi uzturēti jau vairāk nekā piecdesmit gadus, kā arī nacionālās zivju resursu atražošanas programmas ietvaros tiek atbalstītas Gaujas un Ventas lašu populācijas, cenšoties panākt savvaļas krājumu stabilizēšanos ilgtermiņā.