Development of the Traun catchment ichthyofauna in the context of anthropogenic influences

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Statutory declaration

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

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Abstract/Zusammenfassung

Alpine rivers have long been under pressure from humans and climate change, resulting in changes in fish habitat. This thesis investigates the historical occurrence, abundance, biomass, species distribution, and population structure of selected species and their temporal changes considering anthropogenic influences in the rivers Traun, Alm, and Ager by assessing the current fish population and evaluating quantitative stock data of the last 40 years.

The interventions preceded the 14th century and developed into multiple stressors in the last decades, causing adverse effects on the fish population. Additionally, cormorants exert predation pressure on wild fish, especially on *T. thymallus*.

Comparison of quantitative data over the past 40 years shows increases in species and total abundance in the River Traun; the total biomass declined from 1980 to 2009 but increased since. Salmonid biomass shares decreased substantially to 15% in the last ten years, with T. thymallus showing the highest decline. Cyprinids *B. barbus/S. cephalus* increasingly dominate the biomass and *A. bipunctatus/P. phoxinus* dominate the abundance.

The 2019 fish stock survey revealed a severely disturbed fish community characterized by the absence or underrepresentation of indicator species (*C. nasus*) or salmonids (*T. thymallus*, *S. trutta*) in total catch, abundance, or biomass. The most severe deficits are attributable to human impacts, impaired habitats, and limited reproductive success. A climate-induced shift in the fish region from grayling to barbel and further negative impacts of multiple stressors on fish fauna are expected.

To achieve a sustainable improvement of the fish fauna, measures must be implemented for habitat and spawning ground enhancement, reintroducing reference species, conflict resolving between fisheries and bird protection, reduction of cormorant predation pressure, and ecological restoration fisheries management.

Keywords: Alpine rivers, multiple stressors, fish coenosis, deficit analysis, restoration measures.

Alpine Flüsse stehen seit langem unter dem Druck des Menschen und des Klimawandels, wodurch sich der Lebensraum für Fische verändert. Diese Arbeit untersucht das historische Vorkommen, die Abundanz und Biomasse, die Artenverteilung und die Populationsstruktur ausgewählter Arten und deren zeitliche Veränderung unter Berücksichtigung anthropogener Einflüsse in den Flüssen Traun, Alm und Ager, indem der aktuelle Fischbestand erfasst und quantitative Bestandszahlen der letzten 40 Jahre ausgewertet werden.

Die Eingriffe datieren zurück bis in das 14. Jahrhundert und entwickelten sich in den letzten Dekaden zu multiplen Stressoren, die negative Effekte auf den Fischbestand haben. Zudem übt der Kormoran Prädationsdruck auf die Wildfische aus, speziell auf *T. thymallus*.

Der Vergleich quantitativer Daten der letzten 40 Jahre zeigt die Zunahme der Arten und Gesamtabundanz in der Traun; die Gesamtbiomasse ist von 1980 bis 2009 rückläufig, nimmt aber seitdem zu. Die Biomasseanteile der Salmoniden sanken erheblich auf 15 % in den letzten 10 Jahren, wobei *T. thymallus* den stärksten Rückgang verzeichnet. Die Cypriniden *B. barbus*/*S. cephalus* dominieren zunehmend die Biomasse und *A. bipunctatus*/*P. phoxinus* die Abundanz.

Die Fischbestandserhebung 2019 zeigte eine stark gestörte Fischzönose, die durch das Fehlen bzw. der Unterrepräsentanz von Leitarten (*C. nasus*) oder Salmoniden (*T. thymallus*, *S. trutta*) am Gesamtfang, der Abundanz oder Biomasse charakterisiert ist. Die gravierendsten Defizite sind auf menschliche Einflüsse, unzureichende Habitate, und begrenzten Reproduktionserfolg zurückzuführen. Eine klimabedingte Verschiebung der Artengemeinschaft von der Äschen- zur Barbenregion sowie weitere negative Auswirkungen der multiplen Stressoren auf die Fischfauna werden erwartet.

Um eine nachhaltige Zustandsverbesserung der Fischfauna zu erreichen, müssen Maßnahmen zur Habitat- und Laichplatzaufwertung, Wiederansiedlung von Referenzarten, Konfliktbeseitigung zwischen Fischerei und Vogelschutz, Reduzierung des Kormoran-Prädationsdrucks und einem ökologischem Fischereimanagement ergriffen werden.

Keywords: Alpine Flüsse, multiple Stressoren, Fischzönose, Defizitanalyse, Restaurierungsmaßnahmen.

Abbreviations

0+	Fish less than a year old according to length
1+	Fish between one and two years old according to length
2+	Fish older than two years according to length
FIA	Fish Index Austria
HPP(s)	Hydropower plant(s)
LH	Lake Hallstatt
LT	Lake Traun
MQ	Mean annual discharge (m^3 s^{-1})
NGP	National water management plan
PIT	Passive Integrated Transponder
TF	Traunfall
TL	Total length
WFD	Water Framework Directive
YOY	Young of the year

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1 Introduction

The fish fauna in rivers with alpine or pre-alpine characters are subject to constant change and affected by alterations of water quality, hydrology, morphology, and continuity. Fifty-nine percent of the European rivers are affected by water quality alterations, 41 % by hydrology, and 38 % by morphology, while 85 % of the rivers suffer from disrupted connectivity (Schinegger et al., 2012). Factors such as overexploitation, pollution, habitat alteration/fragmentation, changes in discharge regimes, the spread of invasive species, and climate change are mainly responsible for the decline in biodiversity (Geist, 2016; Schinegger et al., 2016). The dramatic decline from the historical richness in fish species and abundance is observed in alpine rivers Drau, Enns, Inn, and Salzach (Anonymous, 1950; Jungwirth et al., 2003; Ratschan et al., 2011; Schmall & Ratschan, 2011).

The central investigation area in this research is River Traun from HPP (hydro power plant) Gmunden close to the tributary River Alm and ~ 7 km of the lower River Alm itself. The assessment also includes the lower course of River Ager until the confluence with River Traun near Lambach. The studied rivers ' entire course is considered in the acquisition of historical information on fish, former quantitative fish stock data, and anthropogenic influences. The current ecological status of the investigated rivers is in large parts moderate, poor, or bad, which gives reason for concern, requests for historic clarification of the causes, and further raises the need for improvement of the situation (Figure 1).

Anthropogenic influences on river ecosystems in Austria date back at least to the Middle Ages. Rivers served as commercial fishing grounds, energy sources for mills, route of transport, source of freshwater supply, and wastewater discharge. Apart from these direct effects, measures in the catchment of rivers indirectly affected the morphology (Haidvogl et al., 2014). In the end, the systematic river regulations in the 19th century and the extensive construction of HPPs in the 20th century led to the monotonous river landscapes and morphological and hydrological destruction of aquatic habitats on a large scale (Haidvogl et al., 2015; Jungwirth et al., 2003). Especially HPPs and impoundments are assumed to negatively impact the original fish species distribution (Jungwirth et al., 2003; Lampert & Sommer, 2007). A significant increase of cyprinid populations and decreased salmonid populations within the impoundment, the underrepresentation of rheophilic species in residual flow stretches, and the emergence of small species have been subject to studies (De Jalon et al., 1994; Lessard & Hayes, 2003). Weirs and dams interrupt the river continuum and represent barriers to many fish species, which are difficult to overcome. Fish are mobile indicator organisms for river continuity. For instance, nase and barbel are known to migrate up to 100 km to their spawning grounds (Jungwirth et al., 2003; Kainz & Gollmann, 1999; Kottelat & Freyhof, 2007). If the longitudinal passage is blocked or bypassed with poorly functioning fish passes, abundances are likely to decrease and even cause the loss of entire populations. The ecological significance of the lateral connectivity between the river and the surrounding area was often completely ignored in the times of large embankment plans (Haidvogl & Winiwarter, 2016; Jungwirth et al., 2014). Tributaries and sidearms were straightened and cut off from the main river, thus preventing the lateral movement of aquatic organisms (Jungwirth et al., 2003). Water quality issues intensified with the growing population and industrialization lacking wastewater treatment plants (Haidvogl et al., 2015). These factors led to a change in fish fauna composition and occurrence.

In the future, a change of physical conditions with advancing climate change is predicted (Lampert & Sommer, 2007). Fish are sensitive indicators reacting to water temperature changes with a shift towards higher elevation and stream distance, causing modified species assemblage and distribution (Comte & Grenouillet, 2013; Jungwirth et al., 2003). Salmonid populations exhibit specific adaptations regarding spawning time, duration and larval development depend heavily on water temperature as the time (Jonsson & Jonsson, 2009).

Fish have complex habitat requirements and are therefore good indicators of the ecological integrity of aquatic systems at various levels, from microhabitat to catchment, which makes the organisms especially sensitive to habitat changes (Chovanec et al., 2003; Jungwirth et al., 2003; Spindler & Chovanec, 1997). Recent studies have shown that grayling stocks with more than 20 kg/ha and a good or excellent age structure today occur in only 6.5% of their original habitat in Austria (Scheikl et al., 2020). Many of the remaining Austrian grayling populations are declining and even threatened with extinction. Therefore, attempts to restore the dwindling populations must be based on methods aiming to reduce the following causes for their decline: migration barriers, river regulation, residual water management, surge and sunk events, destruction of spawning grounds, overfishing, competition, or predatory pressure from other species, including birds (Uiblein et al., 2000). Similar trends are identified in the population of *H. hucho* and *S. trutta* (Scheikl et al., 2020; Zimmerli et al., 2007). Stocking rivers with weak salmonid densities and biomasses with farmed fish has become an essential river management tool to enhance or maintain angling in these rivers (Alexiades & Kraft, 2017). Experiments analyzing the survival of stocked brown trout have shown lower survival than wild fish. However, they can also negatively influence the growth rates of wild populations, but the emigration of wild fish was not proven (Uiblein et al., 2000).

The improvement of the fish ecological status is the subject of the project "Integrated Ecological Water Management at rivers Traun and Alm (IÖG)," initiated by the Österreichischen Bundesforste (ÖBF) and BOKU Vienna (IHG), a project lasting for five years. In total, eight work packages, including fish ecology, fish genetics and health, predators, the survey of the piscivorous bird population, habitat analysis, habitat improvement, management plan, and project management/public relations, are processed. Electro-fishing is necessary to densify the existing information and receive actual fish stock data for rivers Traun, Alm, and Ager. The sampled and stocked fish is immediately marked with PIT tags, which helping to identify the cormorant's influence on stocked and wild fish in the investigated area. The findings are incorporated into an integrated ecological water management plan, which on the one hand, enables sustainable use and, on the other hand, serves to protect nature by developing and implementing management concepts and measures (Ficker, 2020). The evaluation of the currently collected data is not only based on population structure, abundance, and biomass of the current fish stocks but previous surveys from the entire catchment of the studied rivers are included in the analysis and interpretation.

This master thesis describes the historical fish species and fish family assemblage, distribution, and abundance in rivers Traun, Alm, and Ager. In this context, anthropogenic events and environmental parameters to changes in the local fish fauna are the main research element. Quantitative data of recent and prior assessments are further used to substantiate hypotheses concerning the impacts on the aquatic habitat. The analysis and interpretation of data gained in the fish stock survey 2019 is the central empirical component of the presented work.

A distinction from other work is provided by the large time span covered in this thesis to provide a broad overall view of the human demands on a major alpine river and their effects on the ichthyofauna.

2 Research questions and hypotheses

The following research questions and hypotheses have been developed:

First question: Have the typical characteristics of the fish fauna in the investigated rivers changed over time?

> **H1**: Historical fish abundance decreased, native species disappeared, and allochthonous species increased over time.
>
> **H2**: Species composition shifted from salmonid to cyprinid predominance.

Second question: Are deficiencies or tendencies for the fish fauna derivable from the current fish stock survey?

> **H3**: Reproduction and population structure are poor for salmonid species and near-natural for cyprinid species.
>
> **H4:** Species distribution does not correspond to reference conditions.
>
> **H5**: Species immigration and exchange are impaired by deficient migration facilities.
>
> **H6**: Predation pressure by *P. carbo sinensis* reduces the fish stock.

Third question: Are key impacts on the aquatic habitat and the fish fauna attributable to the observed changes in fish metrics?

> **H7**: Aquatic habitat alterations by river engineering, hydroelectric power use, water pollution, and water temperature increase are responsible for changes in fish metrics.

3 Study site

The study area is located in Upper Austria and covers a total river length of 38.3 km, of which 28 km refer to the Traun, 3.4 km to the Ager, and 6.9 km belong to the River Alm (Figure 2; BMLRT, 2020b). The study area at River Traun starts downstream of the HPP Gmunden and ends close to the mouth of River Alm, located around 43 km upstream of the Danube confluence. In total seven sites were selected at the River Traun by covering the whole investigation area, except the large impoundments. Three sites (1 Gmunden, 2 Danzermühl, 3 Steyrermühl) are situated upstream of TF (Traunfall) and the remaining four (4 Traunfall, 5 Kemating, 6 Stadl-Paura, 7 Lambach) downstream of TF. The investigation area should be covered as far as possible. Besides the site of Lambach, all sites are hydrologically impacted by residual water stretches or impoundments (Figure 6). The sampling site at River Alm ranged approximately from the locality of Haresau to the pedestrian bridge near Hafeld. Because numerous weirs and ramps had to be passed, the stretch was divided into eight separate sections. River Ager is investigated in one short portion in the lower reach up to the estuary. The latest ecological status is bad to poor in Rivers Ager and Alm and good for the free-flowing parts of River Traun but shows a moderate or worse ecological potential in the heavily modified areas (Figure 1). The whole study area ranges approximately between 47°56'1.19"N / 13°47'49.55"E and 48°4'58.77"N / 13°54'25.62"E.

The study area includes the "Europaschutzgebiet Untere Traun" (AT3113000) for the most part. Its conservation objective is to maintain or, if necessary, restore a favorable conservation status of bird species listed in Annex I of the "Birds Directive" (§ 5) and their habitats, as well as of migratory bird species that regularly occur in the area (appendix Figure 57). These include, among others, the cormorant (*Phalacrocorax carbo sinensis*) and goosander (*Mergus merganser*). There is a general prohibition of deterioration of the status of the listed bird species (Weißmeier et al., 2011; Zauner et al., 2014). The FFH-area “Unteres Traun- und Almtal” (AT3139000) is located within the “Europaschutzgebiet Untere Traun” in the Trauntal valley between Gmunden and Wels. In addition, a relatively large number of Annex II and V species of the Habitats Directive, including *C. gobio*, *R. meidingeri*, *H. hucho*, and *T. thymallus,* is found here (DORIS, 2021; Umweltbundesamt, 2019).

River Traun drains a large area of the Salzkammergut and sources in the Ausseer basin, where the “Upper Traun” passes Lake Grundl, Lake Altaussee, and Lake Toplitz. In this area, the

Kainisch-, Grundlsee-, and Altausseer Traun merge to the so-called “Koppentraun,” extending to LH in a southwest direction. The “Mittlere Traun” is the north- to northeast-flowing section between LH and LT, passing the city of Bad Ischl. Downstream of LT, the river is referred to as the “Untere Traun” (Lower Traun): the river passes the pre-Alps and the Welser Heide for 73 km, to the Danube estuary near Ebelsberg (~ 260 m.a.s.l.). The gorge section in the deeply incised narrow valley with a stony to gravelly riverbed and interspersed conglomerate blocks ranges approximately from Gmunden to Stadl-Paura (21.5 km). It is generally known as “Traunschlucht,” where the TF is a particularly prominent point at river-km 59.4. River Ager is the main tributary and unites with the River Traun at Lambach on the left bank (river-km 47.9). Other important tributaries are rivers/streams Ischl (left), Gosaubach (left), Krems (right), and Alm (right). The catchment size at Roitham (HZB-number 205252) corresponds to 1,458.4 km^2 with an average MQ of 72.8 m^3/s (1951 to 2016). After the confluence with River Ager at the gauging station Lambach (HZB-number 205468), the catchment area is 2,741 km^2 with a discharge of 108,2 m^3/s (1951 to 2016) (HD OOE, 2020; Pletterbauer, 2009).

The rivers Traun, Alm, and Ager, have always been characterized by intensive anthropogenic use. In addition to the industrial areas at Lenzing (Ager), Steyrermühl, and Laakirchen (Traun), there are seven hydropower plants and six impoundments in the sampling area and another two power plants in the unexamined sections (Siebenbrunn, Traunfall). Although River Traun has been affected by the construction of HPPs and weirs limiting its natural dynamics, 62 % of the investigated stretches are free-flowing (Figure 6; Table 2).

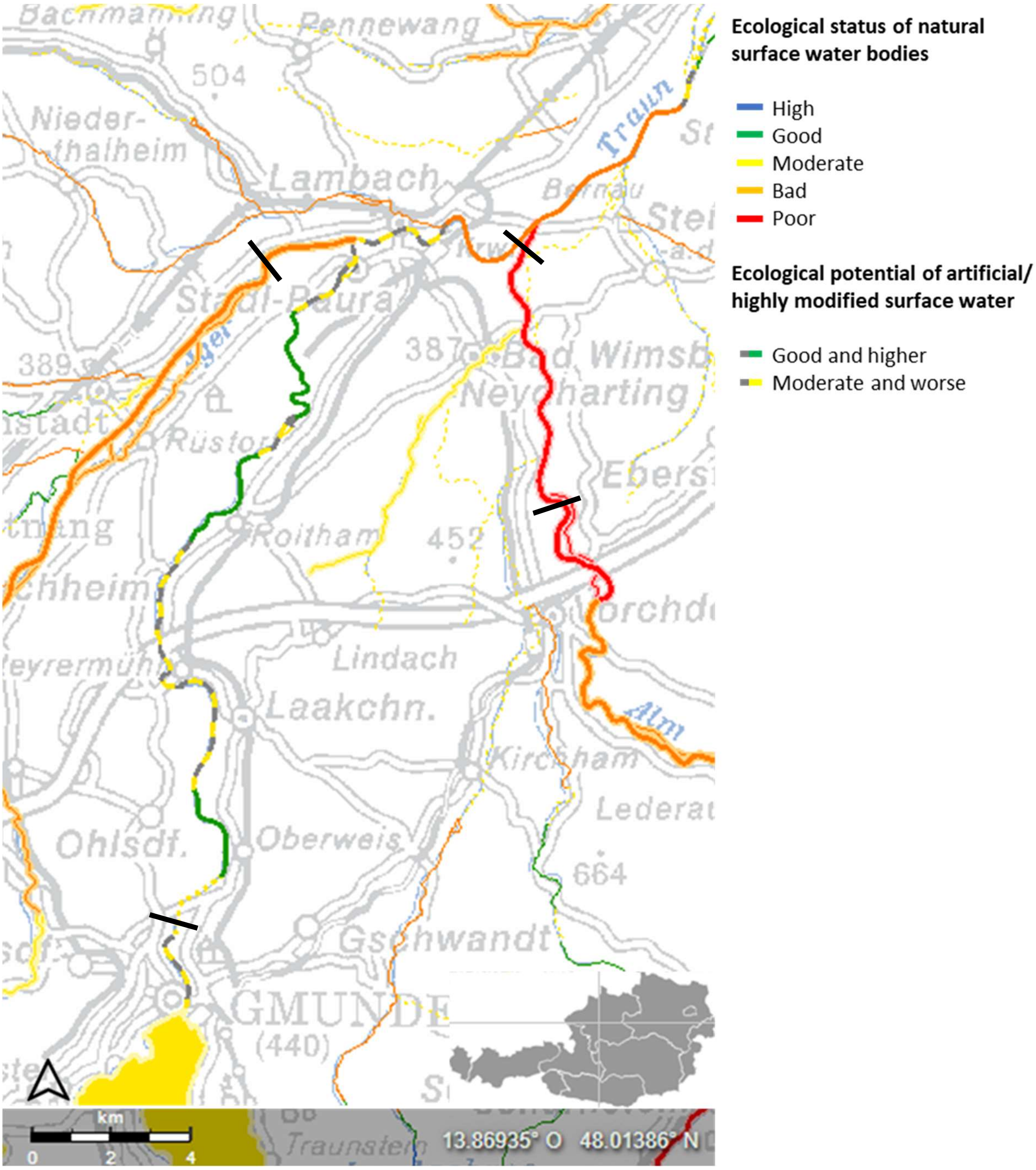

Figure 1: Ecological status of natural and ecological potential of artificial/heavily modified water bodies; study area is within black lines (modified after BMLRT 2020b).

River Alm forms the outflow from Lake Alm, has a total length of around 48 km, and drains the area northward. The largest tributary is River Laudach. The river is largely influenced by engineering measures (weirs, ramps, bank stabilization, flood protection) and numerous water abstractions. From the 6.9 km under investigation, the lowest 3.7 km is a residual water stretch. The River Alm passes two hydropower plants in the investigated area, of which one is under construction; ten weirs or rough ramps interrupt the river course. At the margin of the study area (Alm 8), a 2.8 m high rough ramp at river-km 0.9 represents an impassable obstacle for fish. A small HPP will be newly erected on the right bank, including a fish ladder.

The impoundment areas of the two hydropower plants are relatively short compared to the free-flowing river sections. At the gauging station Penningersteg (HZB-number 205518), River Alm has a mean discharge of 15.1 m^3/s (1966 to 2016), a catchment size of 490 km^2, and a mean wetted width of 29.9 m (BMLRT, 2020a; Pletterbauer, 2009). Because of the partly relatively wide riverbed with gravel substrate, the water flows at shallow depth. The water level was at MQ during the fish sampling.

River Ager is the outflow of Lake Atter at Schörfling and Seewalchen am Attersee and in total 34 km long. In the catchment of River Ager are Lake Fuschl, Irrsee, Mondsee and Lake Atter. At river-km 21.2, the largest tributary, the River Vöckla, unites with the Ager next to Vöcklabruck. The course of the river is oriented to the north, directly downstream of Lake Atter. At Timelkam, the Ager bends to the east and turns into the lowlands between the Alps and Hausruck. From Attnang-Puchheim, its course changes in a north-eastern direction (Pletterbauer, 2009). At the gauging station Fischerau (HZB-number 205450), River Ager drains 1,256.1 km^2, has an MQ of 32.9 m^3/s (1976 to 2016), and a river width of 29.2 m (BMLRT, 2020a). Out of the investigated 3.4 km of the lowest River Ager, the upper area is characterized by a short stretch of residual flow and outflow of HPP Hart. At the mouth, the head of the HPP Lambach impoundment affects the hydrological conditions of River Ager to a minor extent.

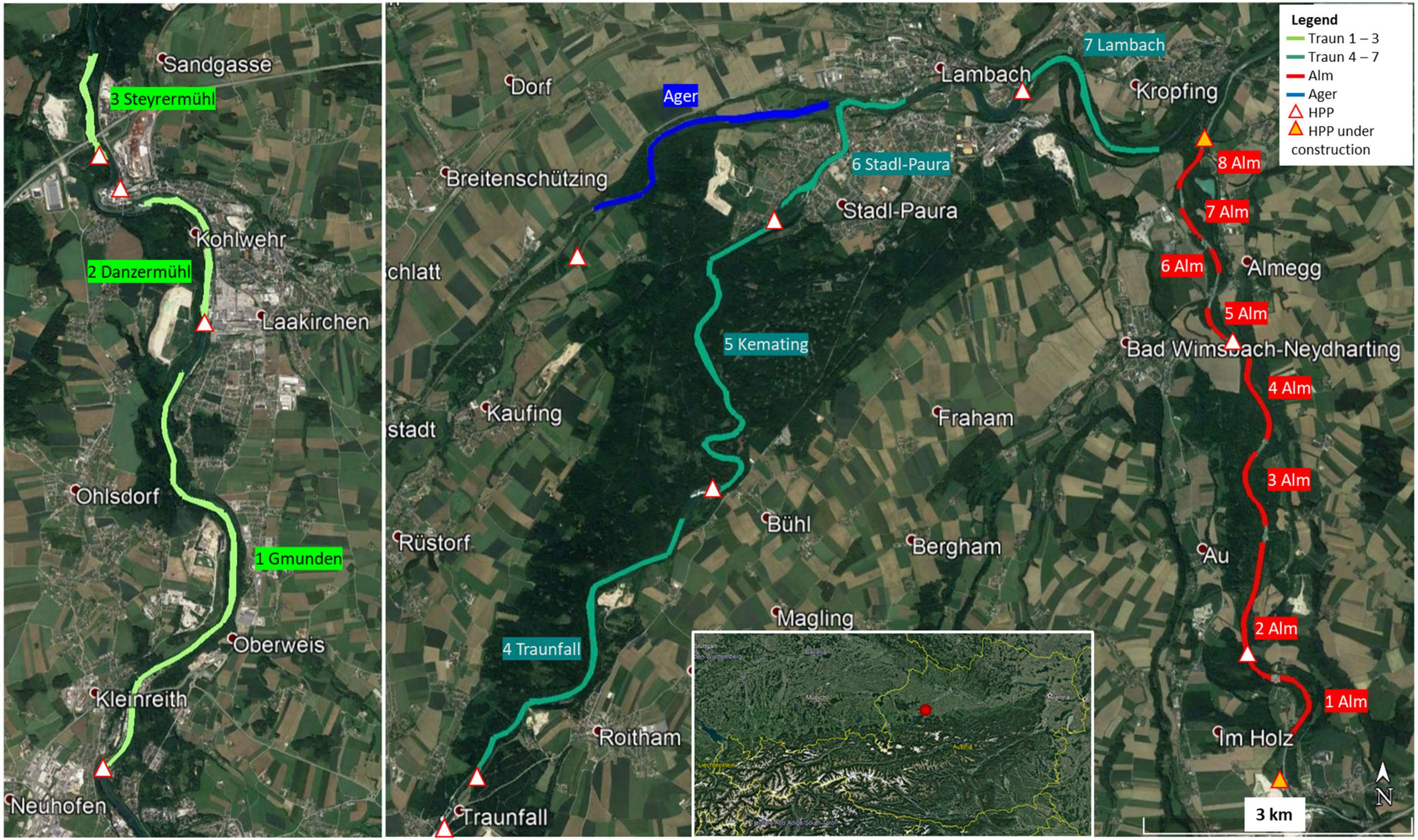

Figure 2: Study site at rivers Traun (light green: sites 1 - 3 upstream TF; dark green: sites 4 - 7 downstream TF), Ager (blue), and Alm (red: eight sites).

Fish ecological classification of the study area

The rivers Traun and Ager the are part of the ecoregion “central uplands” and the bioregion “Bavarian-Austrian Prealps” from LT until their confluence and downstream to the Danube it is referred to as “large alpine rivers.” In the higher reaches of River Traun between LT and LH the bioregion changes to “Limestone Pre-Alps”, while upstream of LH it is part of “Northern Limestone High Alps.” The stream order of River Traun until the Ager confluence is five, and downstream of the confluence is six. The biocenotic region is “hyporhithral large” until the Ager estuary, and “epipotamal large” downstream (BMLRT, 2020b).

Each fish region is defined by the occurrence of dominant or indicator species and the typical accompanying species. The Fish Index Austria (FIA) is a catalog for reference fish communities (“Leitbild”) in defined biocoenotic zones and bioregions. According to their original occurrence without human impacts, species are divided into three classes in the reference list: dominant, subdominant, and rare species (Haunschmid et al., 2017). Due to the special character of the rivers Traun and Ager as lake outflows, the reference fish community differs from the standard, demanding a need for adapted reference species lists. In the case of River Traun (upstream TF), 22 species are indicated, of which five are dominant, nine are subdominant, and eight are rare (Table 5). Downstream of TF to the estuary, three dominant, 15 subdominant, and 21 rare species are potentially found.

River Alm has the stream order five. The reference species assemblage complies with the standard for the “hyporhithral large” fish region with six dominant fish species. Additionally, eight subdominant and three rare species are named in the assessment guideline (Table 8).

River Ager has the stream order six and belongs to the fish region “epipotamal medium.” Four dominant, ten subdominant, and 14 rare species are listed in the reference list (Table 9).

4 Material and methods

The basis of this thesis is the joint analysis of data and information compiled from several sources. In a first step, information from historical sources, data from actual quantitative fish sampling, and data from past fish stock surveys have been transferred to the database and revised before further analyzed. The detailed procedure is described in the following chapter.

4.1 Literature and data processing

Historical data and information are mainly provided by BOKU Vienna IHG. Digital and analog biological information and literature are provided by the Museum of Natural History Vienna (NHM), found in the online platform Zobodat of the Upper Austrian State Museum, the university library of BOKU, the IHG institute library, and several online sources (e.g., https://researchgate.net, https://onlinelibrary.wiley.com, https://scholar.google.de). In addition, data from diploma theses, technical offices, and fish monitoring surveys were gathered and inserted into a data processing program. Local fishery managers provided data regarding stocking quantities. Hatchery and wild fish were tagged before and during the fish stock survey 2019 in order to gain information on the feeding habits of *P. carbo sinensis*. The next step was controlling and correcting the existing data. Lastly, the available data were incorporated, resulting in two data sets with all past and current fish stock assessments.

Literature search is conducted for the entire Traun catchment to get a comprehensive impression of the changes in and around the rivers. The search findings are mainly related to the River Traun and representative of the developments in the other waters in the region and applicable for rivers Alm and Ager, if not mentioned separately. Data from the national water management plan according to the EU WFD are used to analyze the hydromorphological impacts in chapter 5.1.1. In the impact analysis of HPPs and impoundments in chapter 5.1.2, the situation at the catchment level is first described before focusing on the study area.

4.2 Fish sampling and stock calculation

The sampling at River Traun took place from October 21st to 25th, 2019, at River Alm from October 28th to 30th, 2019, and at River Ager on October 24th, 2019. For assessing the existing fish stock, quantitative electrofishing in compliance with the guidelines for the survey of biological quality elements (fish) was carried out (Haunschmid et al., 2017). The obtained data is then used for various evaluations and calculations to assess the ecological status of the investigated area. Therefore, the following parameters are collected in the current study: qualitative data (species distribution, age structure) and quantitative data (abundance, biomass).

In the following paragraph, the electro-fishing procedure and mode of operation are addressed. For field sampling, two different boats in size and equipment are used (Table 1). The big boat is equipped with a 3.5 m wide rake anode that immerses up to 1.5 m into the water. The cathode hangs in the water sideways beside the boat. The electric field is generated between the two poles by a 13-kW aggregator with direct current voltages from 300 V to 600 V. The electric field extends vertically to a water depth of ~ 3 m and laterally to a width of ~ 6 m. At the boat's bow, a platform with railing is installed from where two landing net operators catch the stunned fish and simultaneously serve the dead man's switch. Another person empties the stunned fish from the landing nets into a holding tank. The fishing boat drifts or moves downstream in the direction of the targeted mesohabitat. After each strip, the fish are measured, the catch success is noted, and as many fish as possible with a TL of > 150 mm are injected intramuscularly with 12 mm PIT tags. Apart from *T. thymallus*, which possibly reacts sensible to large tags, fish with a length over 300 mm received a 23 mm PIT tag. Afterward, the tag numbers were scanned into a Biomark HPR Lite reader and transferred to a computer after each sampling day. Except for the boat's dimensions and equipment, the fishing procedure with the medium-sized boat is the same as with the big boat when fishing with the rake anode (Table 1). For sampling of shallow areas or outer banks, mainly a hand anode was used. In rivers Traun and Ager, both boats were used, while in River Alm, the medium-sized boat was sufficient for the purpose of sampling. Limiting factors for sampling by boat are above all water depth and visibility. Bottom-oriented fish species such as *C. gobio*, *B. barbatula*, and *B. barbus*, as well as juvenile generations, are usually quantitatively underrepresented (Haunschmid et al., 2017).

In addition to the regular strip sampling, densification strips were performed to increase the database number of tagged fish for the cormorant monitoring part of the IÖG project.

Table 1: Main characteristics of electro-fishing boats and equipment (Schmutz et al., 2001).

Boat designation	Medium-sized boat	Big boat
Field of application	small watercourses/banks; medium-sized rivers	medium-sized rivers
Length	4.3 m	5.1 m
Width	1.4 m	1.8 m
Weight incl. equipment	250 kg	750 kg
E-generator	5 kW	13 kW
Anode	hand/rake	rake (10 anodes)
Outboard engine	15 HP	40 HP
Crew	3 persons	4 persons

A spatial reference is set up in stock surveys by quantitative sampling and calculation methods. As a sampling of the whole fish zoonosis or its entire habitat is impossible to carry out, statistical methods are used to draw conclusions on the total population. The approach follows the principle of representative sampling by Schmutz et al. (2001). The sampled habitats are selected in situ, considering the natural distribution of each river (-reach). A mean value is formed from the individual strips and weighted according to the strip length for each habitat type. The sampled fish species were captured in specific mesohabitats classified as (shifted) inner/outer banks, midstream portions, or special bank/branch habitats, mainly characterized as side arms, bays, or woody debris.

An average width for each river section[1] was determined using aerial maps/photographs (Google earth) and the measured river widths during field sampling. The width of each strip type is dependent on the size of the boat and the sampling method; the fishing width of the large boat is 6 m, while the effective width of the smaller boat is somehow narrower with 4 m (rake) and 1.5 or 2 m (hand anode). The total width of the river stretch is consequently divided into strips in case of (shifted) inner- and outer banks of 6 m in rivers Traun and Ager and 4 m in case of River Alm. The width of special bank habitats is variable and assigned depending on the conditions on-site and the sampling method. The remaining difference between the total width of the river stretch and the mesohabitats mentioned above are attributed to the midstream sections, which typically have the largest share of the width.

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[1] Gmunden 48 m, Danzermühl 69 m, Steyrermühl 78 m, Traunfall 52 m, Kemating 54 m, Stadl-Paura 52 m, Lambach 58 m; Alm 29.9 m; Ager 30 m

Biomass (kg/ha) and abundance (Ind/ha) are calculated in relation to the different mesohabitat units. First, fish weights are converted using the species-specific length-to-weight relationship. Second, the strip area is calculated from the protocolled width and the length measured from each strip's GPS points. Under consideration of the catch success, the individual weights result in the biomass or abundance for the respective specimen, mesohabitat, and strip. The proportion of each strip in the total surface area of the section (e.g., Gmunden) is further calculated before adjusting the ratio between the actual and desired mesohabitat utilizing a correction factor, reflecting the actual conditions on-site as accurately as possible. In the last step, the uncorrected densities and biomasses are multiplied by the corrected values. To ensure comparability of the data, biomass and abundance are each related to 1 ha of water area or 100 m of river length. Figures and tables were created with the generated data. Species contributing to a minor extent to the abundance and biomass were summarized as “other” species and not presented separately, for instance, in Figure 42 & Figure 43 and listed in the appendix.

Species-specific length-frequency diagrams show the catch number of different size classes and outline reproduction deficits or potential in the fish populations of the respective river. Salmonid and cyprinid species are grouped in species- and length-dependent age classes (0+, 1+, 2+ and above) and evaluated according to the following scale (Haunschmid et al., 2017):

1. all age groups available, natural age structure - young fish dominant
2. all age groups present - juvenile fish clearly underrepresented or adult fish overrepresented
3. Failure of individual age groups, disturbed distribution of age groups (e.g., only juveniles or only adults; subadults are missing)
4. strongly disturbed distribution, mostly very low densities, e.g., only single individuals of different sizes
5. no fish

Exceptions to this classification apply to fish species that may exhibit irregular length-frequency diagrams even in very good condition due to their dietary (piscivorous), modus vivendi (benthic), migratory (potamodromous), or sampling selectivity, such as huchen, pike, barbel, and bullhead.

The differentiation between impoundment, free-flowing, HPP outflow, and residual water sections at rivers Traun and Ager is set by combining NGP maps and data, on-site observation, and protocolling during fish sampling (Figure 6). The differentiation between the free-flowing sections and impoundment is hard to distinguish in the case of River Alm (Table 10). Therefore, the length was not measured, and the only source of information is based on the classification in the sampling protocol. For the abundance and biomass calculations in , the selection is limited to bank mesohabitats because the desired catch efficiency is not achieved in impoundments. The impacted sites at the rivers Ager and Alm are mostly shallow, allowing the consideration of all mesohabitats in Table 10.

5 Results

5.1 Human impacts on the fish fauna of the Traun catchment

Since early times, people have used the River Traun in various and intensive ways, causing adverse effects on the ecosystem. The intensity has changed over time due to improved technological methods (Jungwirth et al., 2003). For instance, river engineering and regulation were carried out in the Middle Ages with the help of willow and timber structures that could not last severe floods. In contrast, in modern times, the hard construction of the banks and straightening of the river course is more permanent. Based on information and literature research by Haidvogl (unpublished) and own research, the importance and demands in the catchment were elaborated, which are shown in Figure 3 (Energie AG, 2020; Land Oberösterreich, 2009; Medl, personal communication, 2019). Until the 17th century, the river had particular importance as a route of transport, primarily related to salt mining, for which the course had to be hydro engineered to a certain extent (Haidvogl et al., 2015; Wohlschlager, 2002). In the next 150 years, water regulation and engineering measures were realized, especially along the River Traun, which mainly refers to lake outflows. Although few fishery records have been found from this period, it must be assumed that it was one of the main uses of the river. From the second half of the 19th century until the first half of the 20th century, large-scale regulation began with the construction of the first HPPs (Table 2).

Despite the problems caused by the construction of dams, the commercial fishery was still thriving. Installing the first water treatment plants in the late 1970s and 1980s gradually solved the problems caused by sewage input from industrial and municipal sources. In the last 20 to 25 years, the connectivity is being gradually improved by installing fish passes and removing barriers in the river. The main period of severe human impacts on River Traun is from around 1850 to the turn of the millennium. Since then, more and more ecological compensation measures have been implemented to restore the ecological integrity of the rivers, but most of the measures, for instance, concerning flood protection and HPP, are irreversible.

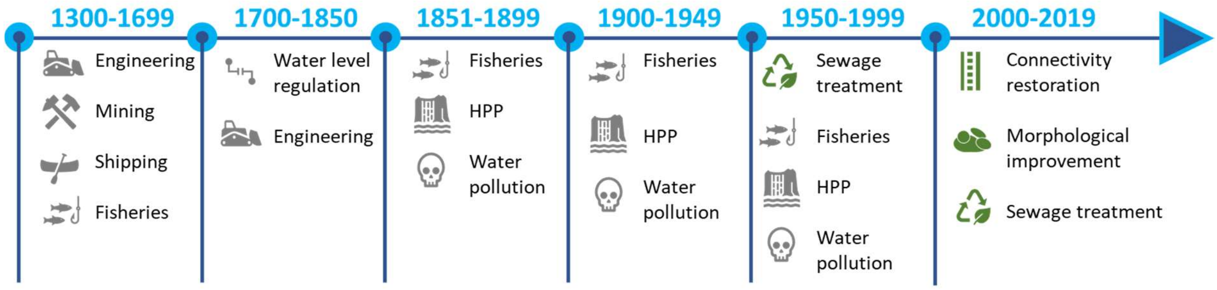

Figure 3: Assignment of central interventions to the periods of their predominant occurrence with positive (green) and negative (grey) impact on the fish fauna in River Traun; based on data from literature research by Haidvogl (unpublished) and own research (Energie AG, 2020; Land Oberösterreich, 2009; Medl, personal communication, 2019).

5.1.1 River engineering, river regulation, and their effects on hydromorphological conditions

Hardly any other river in Austria was intensively regulated and engineered so early on as the River Traun. In order to enhance the riverbed for shipping and log driving, the waterways had to be altered to guarantee the exchange of economic goods (Federspiel, 1992). Riverbed alteration measures began in the early 14th century after discovering salt deposits in the region around Hallstatt. The downstream export of salt and upstream import of food products depended on transport capacities (Federspiel, 1992; Jauk, 2001). Transport ships had to overcome the obstacle of TF and the strong furcation of the river downstream of Stadl-Paura. To ensure a constant water depth, wattle fences were used to unite multiple channels into one, leading to riverbed erosion and further deepening. The structures were not particularly flood-resistant and had to be renewed frequently (Jauk, 2001). Regulation and water abstraction for energy use to drive mills and waterworks was the prerequisite for the economic success in the region and abstracted water from the Traun for this purpose. Flood protection measures became increasingly important, as dikes and embankments preserved the increasing local population from regular flooding and agricultural, personnel, and infrastructural damage. After each flood, the river changed its natural course downstream of the Alm estuary. Due to the low gradient, large areas were flooded in the lower course. Consequently, the demand for consistent regulation increased after each incident (Jauk 2001).

Since the middle of the 18th century, the brushwood or rod bundles for erosion protection were continuously replaced by ashlar structures, especially in villages or roads (Federspiel, 1992). In the middle of the 19th century, the river was straightened, and the banks were secured to an increasing extent with technically complex structures. The changes in the course of the River Traun are especially apparent downstream of the city of Wels, where the river braided initially into many sidearms in the alluvial forest before being constrained to a single channel during large-scale river regulations at the end of the 19th century (Figure 4). Consequently, riverbed incision became stronger when reportedly more than four meters the riverbed eroded between 1885 and 1930. Thus, the groundwater level lowered, the sediment was transported and accumulated in the Traun estuary (Jauk 2001).

Figure 4: Comparison of the River Traun course during the Josephinian mapping from 1775 to 1777 and actual satellite image (Google Earth, 2020; mapire.eu, 2020).

The morphology of the Traun varies greatly between gorges and narrow valleys, while downstream of Stadl-Paura, wide valley floors prevail. Depending on the flow conditions, the substrate consists mainly of gravel of different grain sizes (Kainz, 1992). Bruschek (1959) described the morphological situation of the Traun downstream of TF, a high conglomerate barrier in the river itself, as follows: The riverbed is roughly stony to gravelly, with interspersed rock or conglomerate blocks. The river's width varies significantly with the width of the valley but is usually around 50 to 60 m. According to the author, regulation structures were scarce and had no biological impact on the river. Downstream of Lambach, the hydromorphology was relatively uniform: The riverbed is around 80 m wide; the banks are secured by riprap, and in some places, branches or backwater areas are found. The bottom is covered with gravel throughout, but the impoundment areas are made from sludge deposits in many cases (Bruschek, 1959; Kainz, 1992). During the following decades, the morphological situation of the Lower Traun changed with increasing engineering measures, leading to far-reaching effects on the hydromorphology of the river. According to the latest national water management plan map in Figure 5, banks and riverbed are morphologically strongly modified in the investigated area. However, they have three near-natural sections near Oberweis, Roitham, and Asang ((BMLRT, 2020b). One little modified stretch is found in a short section near the highway bridge in Steyrermühl. Ten[2] sections show strong structural changes; three sections are moderately altered; heavily modified sections do not exist between Gmunden and the Alm estuary. A total of seven impoundment sections with a total length of 10.4 km are lined up between Gmunden and Lambach (BMLRT, 2020b). Large conglomerate blocks are in the river in some parts of the sampling area, mainly located in the gorge section sites between TF and Kemating. Furthermore, the riverbed has no gravel cover in parts of the sites mentioned above and consists of bare rock.

[2] Due to the short length, not all structurally modified stretches are visible in Figure 1.

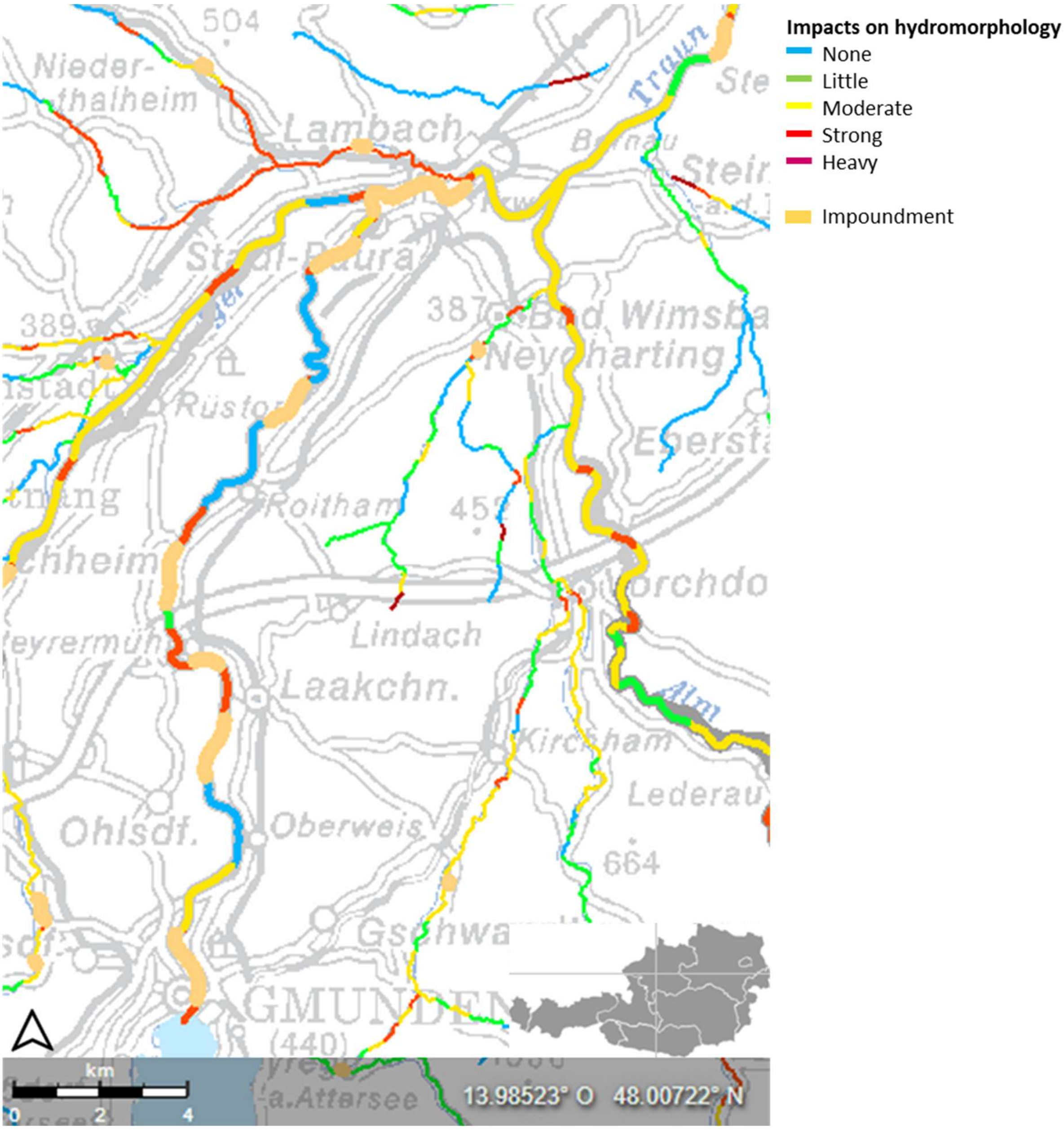

Figure 5: Impact intensity on hydromorphology and locations of impoundments in the investigated area (impoundments ≥ 100 m or > 500 m for catchments > 100 km2 are shown) (BMLRT, 2020b).

River Traun is a river with a comparatively low concentration of suspended solids. The 139 km course is interrupted by LH and LT, two former basins of the Traun glacier acting as sediment and suspended solids traps. Thus, the sediment input quantity of the Lower Traun is mainly dependent on sediment intake from rivers Ager, Vöckla, and especially Alm (Butz, 1985; Zauner et al., 2014). Downstream of LT, the missing sediment leads to riverbed incision and loss of the running water character in impoundment roots and lowering the groundwater level, causing the decoupling and desiccation of floodplains (Jungwirth et al., 2003; Zauner et al., 2014). The incision between Ebelsberg and Lambach was 6 cm/year until 1950 and 14 cm in 1976 alone (Butz, 1985). Through the incision process, floodplain areas are decreasing with the lowering of the water level. Floodplain forests, which inhabit early life stages of fish and other aquatic organisms, are sensitive and threatened ecological hotspots in Austria. The sedimentation of the eroded material takes place in the stagnant water areas before HPPs to a large extent, especially after the Ager confluence In some places, bare conglomerate or rock add to additional biological degradation, causing the loss of macroinvertebrate communities and lithophilic fish spawning habitat (Jungwirth et al., 2003; Zauner et al., 2014).

Downstream of the Vorchdorf Bridge, River Alm was regulated around 60 years ago and forced into a uniform, straight riverbed. Despite this alteration, the morphological situation in the 1990s downstream of the bridge in Wimsbach was referred to as near natural and provided ideal spawning conditions for rhithral species (Hofbauer, 1993). The rivermouth showed a wide variety of ideal habitats for all age groups of brown- and rainbow trout, grayling, bullhead, and burbot (Hofbauer, 1993). Nowadays, the construction of new HPPs threatens the hydromorphological dynamics of River Alm, which is in almost the entire course moderately altered (Figure 5). Two short and strongly modified portions are located near Haresau/Reifenmühle and Bad Wimsbach-Neydharting (BMLRT, 2020b).

5.1.2 Hydropower plants and impoundments

Along the River Traun, numerous mills were built since the Middle Ages (e.g., Kainzmühle, Danzermühle), which small industrial plants replaced during the 19th century. The gorge section downstream of Gmunden is well suited for hydroelectric power production due to the large gradient. Therefore, a series of HPPs were realized in this area (Kainz, 1992; Table 2). Today there are 17 HPPs (excl. Kohlwehr) along the 153 km course of the river, of which 14 HPPs are in the Lower Traun. In total, this results in one HPP every 9 km of the river (or 0.1 HPP/km). Considering the 65 km long Lower Traun, one HPP occurs every 4.6 km (or 0.2 HPP/km). The first turbine-driven HPP of Steyrermühl went into operation in 1868, and others followed in the next decades, especially after World War II the systematic expansion of hydropower took place (Table 2). In this period, *C. nasus*, *R. pigus*, and *B. barbus* were mass abundant fish species, *H. hucho* was still caught frequently in the Lower Traun (Kainz & Janisch, 1987). The development was completed with the construction of HPP Lambach in 1999 (Achleitner et al., 2007). With the construction of the weirs Kleinmünchen, Traun-Pucking, Marchtrenk, and Traunwehr from 1978 to 1984, the fish species described above mostly disappeared or decreased in abundance in the Lower Traun due to the interruption of the longitudinal migration route (Kainz & Janisch, 1987). Many of the HPPs, which have been in operation for over 100 years, have been brought up to the latest technological standards for efficiency improvement during the recent decade. In the renewal process, in many cases, fish passes were built to restore the river continuum, which is addressed in detail in chapter 5.1.3.

Table 2: Hydropower plants and fish passes (storage power plants excluded), Traun (Energie AG, 2020; Heinzel, 2020; Linz AG, 2020; Medl, personal communication, 2019; Zauner et al., 2014).

#	River-km	Completion	Hydropower plant	Last modification		Fish pass	Operator
1	8.1	1978	Kleinmünchen/ Traunwehr	2014		2016	Linz AG
2	14.1	1983	Traun-Pucking			2014	Energie AG
3	24.3	1980	Marchtrenk			2018	Energie AG
4	33.9	1900	Traunleiten	2019			EWW
5	36.2	1940	KW Breitenbach/ Welser Wehr	2006			EWW
6	45.3	1999	Lambach			1999	Energie AG
7	49.2	1911	Stadl-Paura	2013		2013	Energie AG
8	54.3	1911	Kemating	2018		2016	Energie AG
9	58.7	1902	Traunfall	1973			Energie AG
10	59.6	1922	Siebenbrunn			1995	Energie AG
11	61.9	1888	Gschröff			2016	Energie AG
12	63.1	1868	Steyrermühl	2003		2016	Energie AG
13	64.4	1884	Kohlwehr	2018/19*			
14	65	1880	Danzermühl	2019		2019	Heinzelenergy
15	71.2	1968	Gmunden			2017	Energie AG
16	110.9	1962	Lauffen				Energie AG
17	115	Early 20th	Bad Goisern	2016		2016	Energie AG
18	139.9	1993	Bad Aussee				Energie AG

*demolished

The length of free-flowing and impounded river sections in the investigated area of River Traun is shown in Figure 6. The site with the absolute and proportional longest impoundment is Stadl-Paura, where 77 % are impounded. The same share applies to section 3, Steyrermühl. The Lambach site is located entirely in free-flowing parts of the river. Also, high free-flowing shares are calculated in site 1, Gmunden (71 %). In total, 37 % of the sampled area in River Traun is influenced by impoundments, while 63 % is free-flowing. If site Lambach is not considered in the calculation, the share of impounded stretches increases to 45 %.

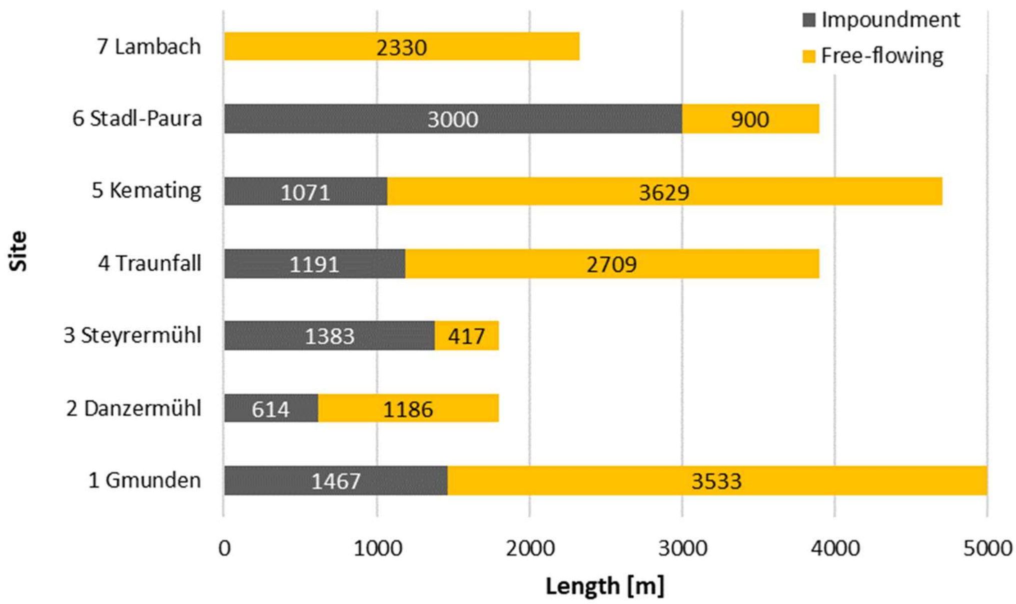

Figure 6: Length of impounded and free-flowing river stretches in the investigated area of River Traun (BMLRT, 2020b).

In River Alm, 44 weirs or gradients existed in the 1990s. Ecological concerns regarding fish passage were not considered in the construction and design of technical structures in that period (Hofbauer 1993). With a total length of 48 km, this corresponds to a barrier every 916 m highlighting the severe impacts by human activities in the river. The residual water dotation after water abstraction by HPPs was regulated weakly by the law, leading to relatively shallow sections downstream of longitudinal barriers. Especially during periods of low water, these parts of the river ran dry, or the remaining water was concentrated in a few remaining pools (Hofbauer, 1993). Near Haresau (~ river-km 9.1) and Hafeld (~ river-km 0.9), two HPPs are under construction in the investigated area now. The numerous rough ramps and weirs, whose function are to impound the river and prevent the groundwater from lowering, are bypassed by fish migration facilities during recent years (chapter 5.1.3; Hofbauer, 1993).

The detailed quantitative effects of impoundments on the fish fauna of the investigated rivers are described in chapters 5.3.4 and 5.3.8.

5.1.3 Fish migration

The fish migration from the Danube into the tributaries was influenced in history early on. The local fishermen at River Traun complained about the Danube fishermen´s method to capture the migratory *B. barbus* and *C. nasus* by blocking the river mouth with nets to increase the catch (Scheiber, 1930). Presumably, a minor number of fish was affected, and the overall impact on the population caused by these fishing methods was reasonably low. The construction of the HPP chain, which initially had neither planned nor implemented fish migration facilities, had an incomparable negative influence on fish migration. The time gap between the construction of the HPPs and their fish passes varies between several decades and more than a century (Table 2). Most of the fish passes were built simultaneously with the modernization of the HPPs since 2010. Compensatory measures for the loss of floodplains were taken in connection with the construction of HPP Lambach by installing additional fish passes at the HPPs Stadl-Paura and Siebenbrunn (Achleitner et al., 2007). According to Zauner et al. (2014), there were no fish passes at the lowest five HPPs or weirs of Kleinmünchen/Traunwehr, Traun-Pucking, Marchtrenk, Traunleiten, and Breitenbach/Welser Wehr until 2014. In the same period, the fish passes in the study area of River Traun did not (HPPs Lambach, Kemating, Siebenbrunn) or not fully (HPPs Stadl-Paura, Gschröff, Siebenbrunn) meet the requirements of the state guideline for the construction of fish passes (BMLFUW, 2012). The fish pass at HPP Danzermühl already met the technical specifications before its renewal in 2019. Subsequently, some fish ladders were renewed to meet the guideline requirements (see Table 3). Due to the drifting/migration of fish from and back to LT, the uppermost HPP of Gmunden is of particular importance regarding the biological passability, where a fish elevator was installed and monitored in 2017 and 2018 (Mader, 2019). Due to the alternating operation of the fish lift, it represents at least a temporary obstacle to migration, especially during the main migration season in autumn, fish may accumulate in large numbers at the entrance of the transport cage. Salmonid species and barbel show deficits in the continuation of a directed migration movement. Another weakness of the fish lift system is the unsatisfactory situation at the exit. The transported fish rarely swim out of the transport cage actively with the current of the flushing surge. Instead, the fish show a pronounced escape behavior from the suddenly occurring, changed hydraulic conditions; also, the fish descent is technically impossible and was not considered in the overall evaluation score of 2.33 (Mader, 2019).

The lowest fish pass in River Traun is the Traunwehr 8.1 km upstream of the Danube. It is assumed that only a few individuals of the fish that attempt to overcome the weir through the fish pass are also successful in the attempt (Zauner et al., 2014). The next fish pass at Traun-Pucking is hardly passed by a tenth of the fish that overcome the lowest facility, which thus has a thinning effect on the population of migratory species (Jungwirth et al., 2003; Zauner et al., 2014).

At the River Alm, the need for suitable fish passes was recognized in the 1990s (Hofbauer, 1993). A series of fish passes and modifications on the numerous rough ramps have been realized in recent years to improve the fish migration possibilities. Today, River Alm is passable for fish by either fish passes or modified rough ramps in the investigated area (BMLRT, 2020b). The lowest ramp near Hafeld at river-km 0.9 appeared very steep during the on-site survey. A separate fish pass was not installed, limiting the passability and migration potential for at least some relevant fish species (e.g., weak swimmers and large species as *H. hucho*) and must therefore be considered critically, according to Ratschan et al. (2020). A fish pass will be included in the HPP currently under construction, which will improve the situation in the future (compare chapter 5.1.2).

5.1.4 Water quality

Water quality started to alter by human activities in the Middle Ages when the roasting of hemp or by rotting processes to obtain the fibers. However, it was already recognized that this process produced harmful substances to fish (Jungwirth et al., 2014). Although there are no studies on the water quality, it must be assumed that the river's water quality worsened by the population increase and expansion of the production in the period of the industrial revolution.

Various authors described the situation concerning water quality in the investigated area in the 1950s and 1960s as follows (Bruschek, 1959; Butz, 1985; Hager, 1965; Kerschner, 1956; Werth, 1969): The organisms of the Lower Traun are mainly influenced by the very different flow and depth conditions due to damming and regulation, as well as by the discharge of wastewater. As a lake outflow, the Lower Traun initially carries hardly any suspended solids and is therefore very clear. The municipal sewage of Gmunden was discharged into the Traun downstream of LT and had a positive fertilizer effect in a biological production sense. However, downstream of Danzermühle, two wood-grinding mills and the paper mill of Steyrermühl (60 t pulp/day according to the sulfite process) discharged into the river, causing a considerable deterioration in water quality. Downstream of the wastewater discharge point, thick wastewater fungi were found on the riverbanks, and the otherwise transparent greenish water became turbid. The downstream effect of the wastewater was particularly strong in and between the impoundments of Siebenbrunn and Marchtrenk, where the deposition of wood fibers, sewage fungi, and regular sediments accumulated. The biocoenosis indicated strong organic pollution, and the impoundment was designated as an inadequate clarification basin for the industrial wastewater. In the remaining 12 km from Danzermühl to the Ager estuary, the conditions improved again in the areas with higher water velocity, despite other HPPs and two further impoundments.

The condition of the Traun has deteriorated considerably with the inflow of the heavily wastewater-polluted River Ager, transporting the wastewater from the cellulose factory Lenzing (150 t pulp/day) and the rayon/cellophane factory (100 t/day). The so far still predominantly greenish watercolor turned brownish, and the flocculation increased considerably. Thus, the condition of the Traun seemed to improve downstream of the unimpacted Alm estuary, while in the lower part of the Wels impoundment, wood fibers and sludge were deposited. In deeper layers, anaerobic degradation processes produced substances harmful to fish, e.g., hydrogen sulfide, methane, and carbon dioxide. Therefore, the Traun must be described as heavily wastewater polluted from the Ager to the Danube in the 1950s and 1960s. The fact that the harmful effects of the high wastewater volumes were not more significant is a consequence of the turbulence in the free-flowing sections, repeatedly enriching the water with oxygen and increasing the self-cleaning capacity of the river (Bruschek, 1959; Butz, 1985; Hager, 1965; Kerschner, 1956).

In 1975, the water quality in the Lower Traun in the area up- and downstream of HPP Gmunden corresponded to quality class I to II, worsening to quality class II after the discharge of wastewater treatment plant Traunsee-Nord (Figure 7). Again, the paper mill Laakirchen deteriorated the quality, but the leading polluter was the paper mill in Steyrermühl. The quality class in the impoundment Siebenbrunn reached class III. The highest biological degradation with a water quality drop to III and III - (IV) was detected in the free-flowing stretch near Roitham, HPP Kemating, and Stadl-Paura. The highly loaded River Ager worsened the water quality again, as oxygen depletion in the sedimented substrate became the main problem to aquatic organisms in the impoundment near the city of Wels. The water quality after Wels sank to IV, caused by the exclusively mechanical clarification of municipal wastewater (Werth et al., 1978). The River Alm had a relatively low pollution level in the 1970s, coming from untreated municipal wastewater. The water quality class ranged between I and II (Hauer, 1997; Werth et al., 1978).

The wastewater input into the Traun was drastically reduced with the commissioning of the biological treatment plant of Lenzing AG in 1987 (Kainz & Janisch, 1987). The detailed, in general, positive effects of the treatment plant on the ichthyofauna are subject to the thesis of Wohlschlager (2002). The water quality improved in general in rivers Traun and Ager in 1991/1992 as extreme contamination was not proven anymore (Figure 7). In November 1991, however, an incident at Lenzing AG occurred when a pipe with chlorine bleach ruptured and decreased the fish population in the Ager drastically. Around three tons of dead fish had to be removed from the river, consisting of trout up to 5 kg, pike up to 15 kg, barbel up to 5 kg, and grayling up to 55 cm. The river was practically dead, besides a few remaining *S. cephalus* individuals surviving the catastrophe (Hauer, 1997). Decisive restoration steps were taken at the rivers Traun and Ager, and large-scale investigation programs of the new environmental situation were initiated. Wohlschlager (2002) observed a steady increase in abundance, biomass, and species number after the accident between 1991 and 1994.

Water quality analyses in 2002 show further improvement in the rivers Traun, Alm, and Ager. River sections with heavy contamination disappeared utterly. Moderate contamination predominates at Ager and Traun, while at the Alm, the water quality is even better, ranging between I and II (Figure 7).

The evaluation scale was expanded to include the category unsatisfying in the last water quality survey from 2015 to 2017. The water quality at the rivers Traun, Alm, and Ager is classified as high or moderate (Figure 7). In the last decades, the installation of sewage treatment systems has minimized the adverse effects of poor water quality on grayling and other salmonid populations in alpine rivers (Uiblein et al., 2000).

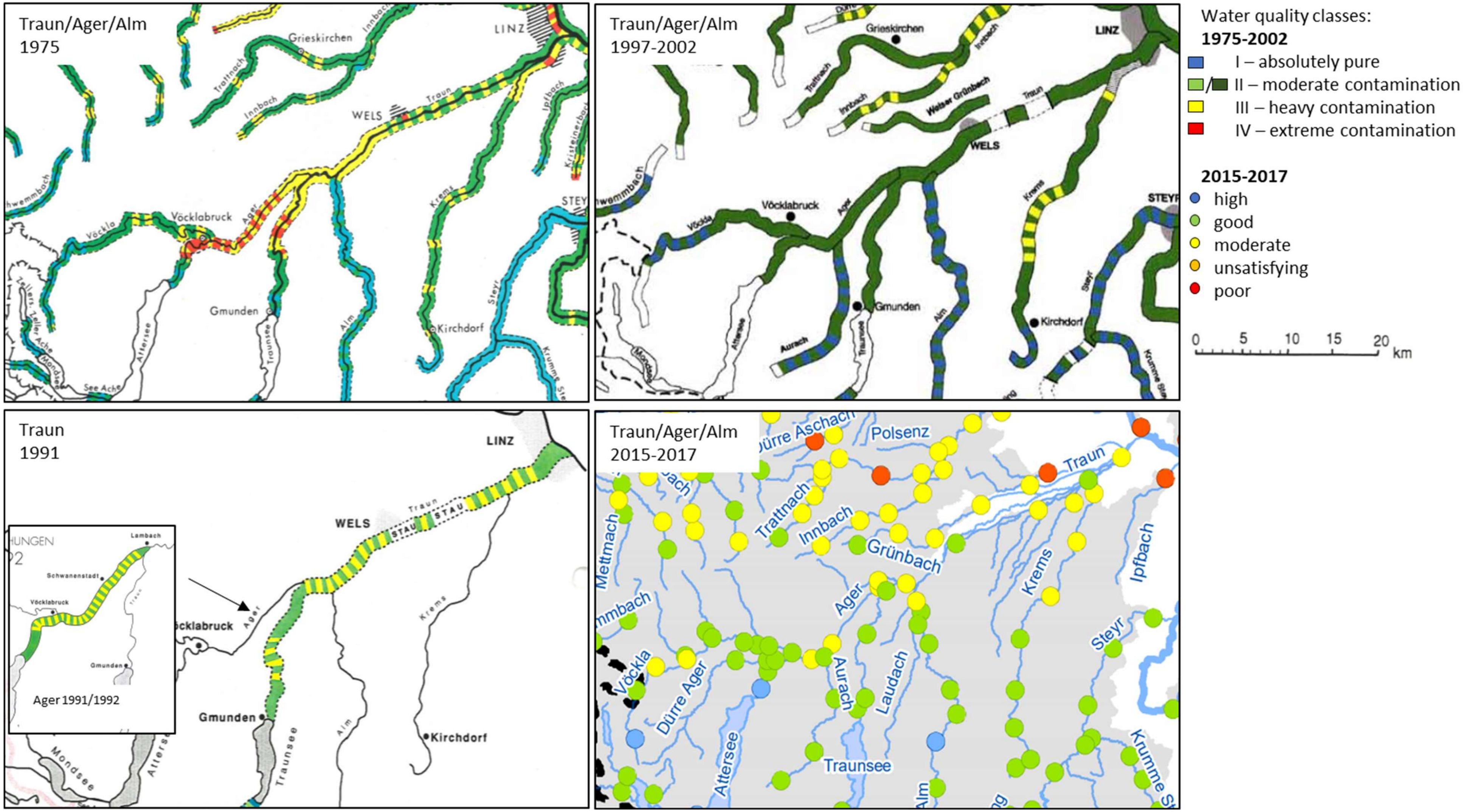

Figure 7: Development of the water quality at Traun, Alm, and Ager (Bachura et al., 1992, 1993a, 1993b; Land Oberösterreich, 2017; Werth et al., 1978).

5.1.5 Temperature

Factors for the formation, composition and distribution of aquatic communities are highly dependent on the temperature regime of rivers. Most freshwater organisms, especially invertebrates and fish, are poikilotherm. Metabolism and thus respiration, digestion, growth, activity, and reproduction are dependent on the environment's temperature (Jungwirth et al., 2003).

The River Traun passes several lakes in the headwaters and middle reach, whose temperature rises more rapidly than running waters in summer and are colder in winter caused by the drainage of cooler surface water. These extremes are even more pronounced at River Ager than at River Traun because of the synergistic effects between a higher proportion of lake surface in the Ager catchment, the lower discharge, and warm water emitters along the river (Pletterbauer, 2009; Walder, 2009). Thus, minor changes in water temperature may be a limiting factor for the survival of individual species or at least certain life stages if the water temperature increases to an extent where the habitat conditions do not meet the requirements of a fish species (Pletterbauer, 2009). Thus, climate change and the increase in temperature are one of the most critical constraints on fish distribution, causing a predicted 70 m altitude shift of fish communities, triggering a competition between salmonids and cyprinids, and the reduction of habitat availability (Comte & Grenouillet, 2013; Matulla et al., 2007). In Austria, this development will lead irrevocably to a shift in fish regions, particularly in rivers passing a lake in their catchment (Melcher et al., 2013).

Rising temperature has another effect on the reproduction success and ability of salmonid fish. Different life stages have different temperature tolerance ranges. For instance, reproduction takes place within a particularly narrow water temperature range. *S. trutta* and *T. thymallus* eggs show sensitivity to reduced oxygen saturation in the interstitial, associated with rising water temperature (Jungwirth et al., 2003; Pletterbauer, 2009). In the rivers Ager and Traun, the factories of Lenzing AG, UPM Kymmene Austria GmbH, and Heinzel Paper AG emit warm water into the rivers, causing the additional thermal rise in water temperature. The difference to the natural temperature state is much higher in the winter than in the rest of the year. During the summer months, water temperatures with peaks above 25 °C for consecutive days are common in River Ager and accelerated by industrial hot water discharges

(Pletterbauer, 2009). As a result, the upper temperature optimum for salmonids of 19 °C is exceeded frequently, representing an important stressor to the natural stocks of *T. thymallus* and *S. trutta* (Jungwirth et al., 2003; Pletterbauer, 2009).

5.1.6 Commercial fisheries

Commercial fisheries were of great importance in alpine waters until the 20th century. Rivers and streams were intensively fished using a wide variety of methods. Fish was an important food source and supported the local community with income, but meant a decline for some fish species in stocks centuries ago (Jungwirth et al., 2003). The harvest of the so-called "Spretzlinge," which are one-summer aged grayling and a demanded delicacy at that time, had a particularly negative impact on the grayling stock. The government reacted with a total ban on the sale of juvenile grayling (Walder, 2009). As early as 1610, the salt authority in the region maintained its own fish tank downstream of TF, which always had to be filled to transport fish to Vienna at low water (Wacha, 1956). River Traun and LT were an export area for fish, but a large quantity was also consumed in the tourism sector in the area itself (Krafft 1874). For example, in the district of Gmunden (LT and River Traun), 860 kg of Cypriniformes, 1,925 kg of Salmonidae, and 888 kg of pike, perch, and other species were captured annually in the late 19th century. In the fishing waters of Lambach (LT and Ager), 2,500 kg of Cypriniformes, 1,238 kg of Salmonidae, and 75 kg of fish from other families were harvested annually.

In the fishing districts of Lambach Abbey (Traun with lower reaches of Ager and Alm; approx. 80 to 90 ha), which had an important position in the Traun fisheries, *C. nasus* was the most frequently caught species with > 2,000 kg/year from 1774 to 1783, before declining to 768 kg/year in the following period (Figure 8). In the same period, *B. barbus* shows a decrease in yield from 519 to 124 kg. The species was captured either by fishing rod, net, or trap with the minimum harvest size of 25 cm and was one of the most important at the Linz fish market, where its market share increased from 4.5 % in 1905 to 12.5 % in 1954 (Kerschner 1956; Krafft, 1874). Furthermore, 223 kg of brown trout was harvested from 1774 to 1783 on average, but between 1803 and 1810, only 33 kg/year were reportedly removed in the fishing district (Scheiber, 1930). In the second half of the 19th century, 560 kg of trout and 168 kg of lake trout were annually caught in the fishing district of Gmunden, including LT and parts of the River

Traun (Krafft, 1874). The high value of brown trout was seen in the fact that Lambach Abbey operated its own trout fish farm for stocking purposes (Wittmack, 1875). In the years 1774 to 1783, 45 individuals of *H. hucho*, each weighing 6.2 kg on average, were captured. From 1803 to 1810, the catch dropped to 132 kg, which is < 50 % of the yield from the previous period (Haidvogl and Waidbacher 1997). From 1920 to 1950, the fishing in the district of Lambach Abbey was performed by Karl Puchner. According to his catch statistic, grayling and nase were the most frequently captured species, but also trout, barbel, chub, pike, and huchen were captured, although the fish stock overall was significantly lower compared to previous times (Wohlschlager, 2002).

The yield numbers reflect the high abundance of salmonid and cyprinid stocks, especially of *C. nasus* and *T. thymallus*, in the Lower Traun before the 20th century. However, commercial fishing decreased steadily in the following decades, up to the complete collapse. For instance, ~ 82,000 fish from 32 species were sold at the Linz fish market from 1902 to 1905 before decreasing to < 10,000 from 18 species in 1954 (Kerschner, 1956; Wacha, 1956). From that point on, recreational fishing became more and more popular, creating a new source of income for fishing rights holders (Wohlschlager, 2002).

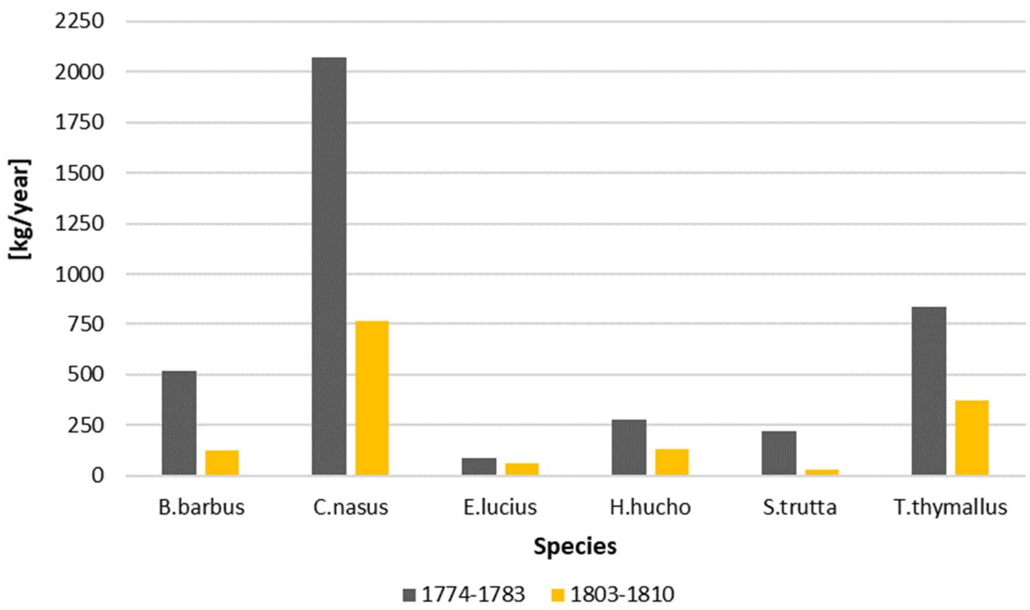

Figure 8: Average annual yield [kg/year] in the fishing area of Lambach Abbey in 1774 to 1783 and 1803 to 1810.

5.1.7 Stocking

Fisheries management and/or stocking policy alone has not quite such long-term effects as changes in habitat but still substantially impact natural fish communities and stocks (Jungwirth et al., 2003). For example, an excerpt from the diary of Abbot Pagl, who headed Lambach Abbey, shows that trout stocking began in the early 18th century. However, his records do not contain information on whether its purpose was to increase the fish population in certain sections of the fishing district or whether there were fish farming ponds without connection to the mainstream (Wohlschlager, 2002).

In recent times, the Lower Traun was subdivided into four recreational fishing areas, of which two are in the investigated area between river-km 73 to 43. In 1955, licenses were issued for approximately 1,000 fishing days. The catches amounted to around 400 kg, the stocking quantity of 0+ grayling and 1+ trout was around 100 kg. The number of fishing days increased to 3,000 in 1964 and 5,000 in 1979. Stocking of trout and grayling was increased in the following years, namely 500 kg in 1964 and around 1,000 kg in 1979. Further downstream outside of the study site, mainly trout between 5,000 and 10,000 kg were stocked in 1979. In that year, the salmonid fish stock between Marchtrenk and Traun-Haid was estimated at 1,000 to 1,300 kg/km, corresponding to around 138 to 180 kg/ha with the present river width of 72 m (Butz, 1985).

After the chlorine bleaching accident at the Ager in 1991, particular importance was given to the re-establishment of the original fish population by re-stocking measures. For this purpose, not only catchable-sized salmonids were stocked, but primarily fry and 1+ fish. Naturally, small fish species and whitefish were also considered in the restocking process. According to older reports, there was a healthy *H. hucho* stock in the Ager before 1938, leading to the start of a motivated reintroduction project with 0+ to 4+ individuals. According to the fishery managers, these measures resulted in healthy fish stock in the Ager the following years after the incident (Hauer, 1997). Although stocking alone is not solely the reason for a good fish stock with natural species composition, the habitat quality is usually the limiting factor for natural fish stock development (Jungwirth et al., 2003; Uiblein et al., 2001).

Figure 9: Examples of stocked fish in Rivers Traun and Alm in 2019.

The numbers of fish that were tagged in the scope of the IÖG project in 2019 are shown in Table 3. However, the stocking figures in Table 3 are a snapshot given as an example, as it must be assumed that the actual stocking quantities are somewhat higher. According to the managers, salmonid stocking is still taking place. Overall, the fish were stocked in catchable size with an average length of 330 mm (Traun), 295 mm (Ager), and 337 mm (Alm).

Depending on the fishing district, the amount of rainbow trout at the Traun differed from approximately 3,400 in the area of the fishing club "Freunde der Gmundner Traun" to 1,900 individuals in the district of "Steyrermühl." Furthermore, around 2,800 individuals were stocked in the fishing waters of "Stift Lambach." Compared to the *O. mykiss* input, 250 individuals of *S. trutta* were introduced in the Stadl-Paura site. The input is calculated by the division of the total weight and site area. The highest input was performed between the sites Danzermühl and Steyrermühl (103 kg/ha), where around three months later, another 68 kg/ha were introduced.

Table 3: Stocking figures of 2019 in the rivers Traun, Alm, and Ager; Alm is calculated as one site with an area of 24 ha.

River	Date	Species	Club	Site name	Number (appx.)	Total weight [kg]	Site area [ha]	Stock 2019 [kg/ha]	Input [kg/ha]	Stock – Input [kg/ha]
Traun	22/06/19	*O.mykiss*	Freunde der Gmundner Traun	2 Danzermühl - 3 Steyrermühl	2,937	800	8	?	103	?
	05/07/19	*O.mykiss*	Stift Lambach	6 Stadl-Paura	802	400	30	3	13	-10
	24/07/19	*O.mykiss*	Steyrmühl	4 Traunfall	1,200	351	29	2	12	-10
	23/08/19	*O.mykiss*	Stift Lambach	6 Stadl-Paura	800	373	30	3	13	-9
	06/09/19	*O.mykiss*	Stift Lambach	6 Stadl-Paura	350	108	30	3	4	0
	27/09/19	*O.mykiss*	Freunde der Gmundner Traun	2 Danzermühl - 3 Steyrermühl	900	525	8	?	68	?
	04/10/19	*O.mykiss*	Steyrmühl	4 Traunfall	700	207	29	2	7	-5
	11/10/19	*O.mykiss*	Stift Lambach	6 Stadl-Paura	600	217	60	3	4	0
	03/07/19	*S.trutta*	Stift Lambach	6 Stadl-Paura	250	120	30	3	4	-1
Alm	05/07/19	*O.mykiss*	Stift Lambach	?	802	400	24	15	17	-2
	29/08/19	*O.mykiss*	Stift Lambach	Alm 3	900	311	24	15	13	2
	03/07/19	*S.trutta*	Stift Lambach	?	250	120	24	14	5	9
	19/07/19	Trout*	Stift Lambach	Alm 3	700	272	24	15	11	3
Ager	09/08/19	*O.mykiss*	Stift Lambach	Ager	500	124	13	5	9	-4
	06/09/19	*O.mykiss*	Stift Lambach	Ager	350	108	13	5	8	-3

* *S. trutta* and *O. mykiss*

5.1.8 Predatory pressure of piscivorous birds

Cormorant (*Phalacrocorax carbo sinensis)*

Predatory birds are not a human impact in a direct sense but are influenced by humans as target species in wildlife management strategies and therefore referred to in this chapter. The impact of *P. carbo sinensis* on wild fish stocks is a controversial topic of public interest and is therefore not part of this analysis. Instead, this chapter focuses on the development in cormorant numbers and the presentation of the first results of the cormorant monitoring study of the rivers Traun, Alm, and Ager.

The cormorant takes prey fish between 30 mm and 500 mm, but the size preferably ranges between 200 mm and 350 mm; the values given in the literature for the average daily feed requirement vary between 270 and 750 g, while the demand tends to be higher in winter (Jungwirth et al., 1995; Keller et al., 1996; Uiblein et al., 2001). *P. carbo sinensis* is a distinct opportunist in prey selection and water depth but usually hunts in groups in a water depth of one to three meters (Uiblein et al., 2000). According to Jungwirth et al. (1995), in lakes and large rivers with high cyprinid and percid stocks, these species appear to be favored, while in salmonid- and grayling-dominated waters, the proportion of these prey fish increases to up to two-thirds, in some cases to almost 100%, depending on the availability. In the wintering area, the species gather at collective resting or sleeping places where they usually relieve excrements and pellets. The radius of action around the sleeping place can be up to 60 km (Uiblein et al., 2000).

The main distribution area of the cormorant in Austria has been the Danube, while the first sighting of *P. carbo* in Upper Austria was a small breeding colony that appeared near Raffelstetten from 1944 to 1957. However, the species became extinct in Upper Austria in the mid-1950s (Uiblein et al., 2000). The species has been frequently sighted in Upper Austrian rivers in the winter months since the beginning of the 1970s. Cormorants have been observed since the winter of 1989/90 in the Lower Traun, while in the Middle Traun and at the rivers Krems, Ager, Alm, and Vöckla, the birds have been evidenced since 1992/93. The Europe-wide total protection of the species has led to continuously recovering cormorant stocks in recent years (Kainz, 1994; Uiblein et al., 2000).

The cormorant census from 2000 to 2010 is shown in Figure 10. The number of birds at the sleeping trees, which are within the reachable range of the investigation area, is increasing with an upward trend. The average and median individual numbers were < 50 each in the 2000/2001 season and reached > 300 in 2019/2020. With higher bird density, the predation pressure on fish also increases.

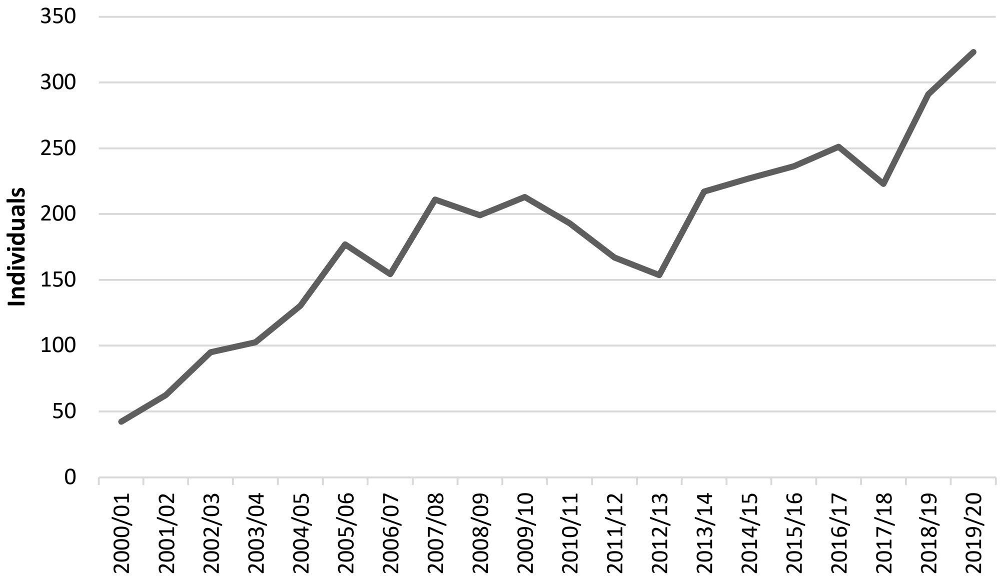

Figure 10: Average cormorant numbers in the investigation area; counting season 2000-2008 from September to February; since 2008 July to February (based on Eisner, 2017; Pfanzelt, 2000).

The preliminary results of the cormorant monitoring are shown in Table 4. The intention is to indicate the feeding pressure on the fish in the study area but cannot be regarded as entirely representative, as long-term records are required, which were not yet available at the time of analysis. In total, 239 out of ~ 3,300 tagged individuals were retrieved under the cormorant roosting sites at the Traun, representing 7 % of the initial number. At the Ager and Alm, 7 % and 5 % of the rainbow trout tags, respectively, were recovered. In contrast, cormorants affect rainbow trout of unknown origin to a different extent: At the Traun, one out of twelve tagged wild fish was predated, cormorants caught 11 % from River Alm. *P. carbo sinensis* selects preferably rainbow trout between 280 and 339 mm in TL, as > 80 % of the retrieved individuals are in between this size range (Figure 11). Hardly any fish below 220 mm and above 380 mm are taken, which means that the feeding pressure is mainly on stocked trout, as the stocked fish size and range overlap considerably with the fish taken by the cormorants.

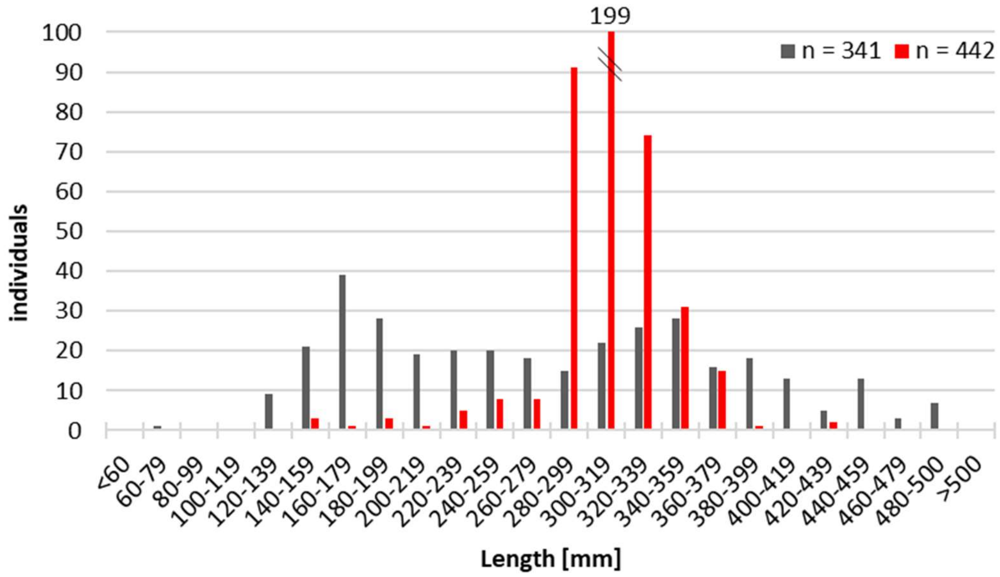

Figure 11: Length-frequency diagram of all O. mykiss sampled 2019 during quantitative sampling (grey) and those found at cormorants sleeping trees (red).

S. trutta stocked at the Traun is retrieved to 3 % at the cormorant trees. The stocked individuals at River Alm show a 15 % predation probability. Feeding ratios for brown trout of unknown origin at rivers Traun and Alm are slightly lower at 12 % each. In the case of *T. thymallus*, no stocking of subadult or adult fish was performed in 2019, so the only tagged individuals are wild fish. The highest feeding ratio of 33 % is recorded from grayling originating from River Alm. Cormorants feed on graylings from River Traun slightly less frequently (31 %). In total, 34 out of 109 tagged individuals were identified under the sleeping trees. At the Ager, the cormorants removed 20 % of the PIT-tagged *T. thymallus*. In Figure 12, the size selectivity of *P. carbo sinensis* on *T. thymallus* is displayed. The highest probability of predation is for adult graylings with a TL between 300 and 319 mm, which is also the most frequent size class in the investigated rivers. *P. fluviatilis* and *E. lucius* are other essential prey species for cormorants at the Traun; 23 % and 21 % of the tagged fish are attributed as prey to the birds.

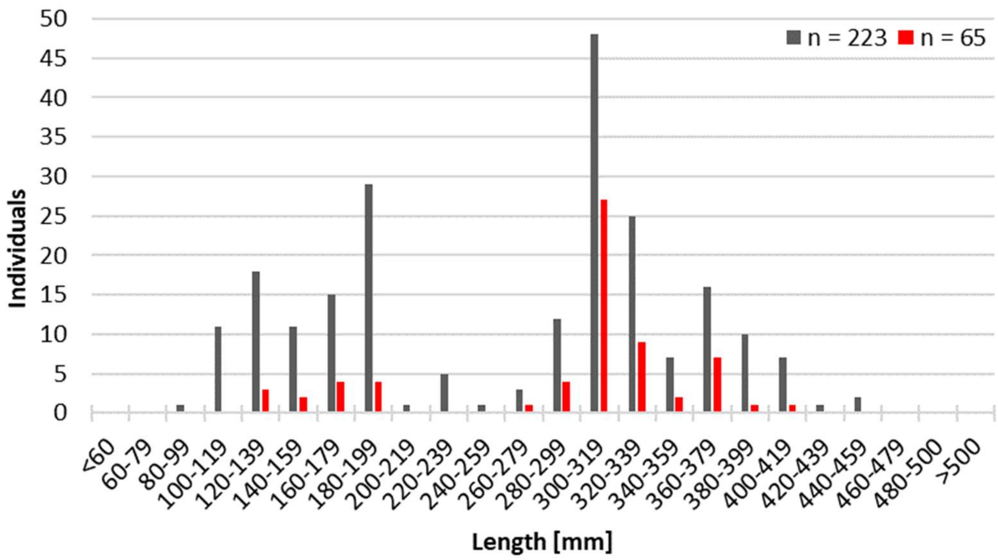

Figure 12: Length-frequency diagram of all T. thymallus sampled in 2019 during quantitative sampling (grey) and those found at cormorants sleeping trees (red).

Table 4: PIT-tag monitoring results from 10/2019 to 04/2020 as part of the IÖG study on the cormorant predation pressure on the fish stocks in the investigated rivers Traun, Alm, and Ager; umber of tagged is compiled from includes densification- and stock assessment strips.

			Tagged			**Retrieved**			
River	**Origin**	**Species**	Number	Ø Length [mm]	Range [mm]	Number	Ø Length [mm]	Range [mm]	**Feeding ratio**
Traun	Wild	*B.barbus*	274	293	120 - 670	1	155	-	0.00
Traun	Wild	*E.lucius*	39	352	175 - 765	8	299	185 - 430	0.21
Traun	Wild	*O.mykiss*	12	137	140 - 250	1	185	-	0.08
Traun	Wild	*P.fluviatilis*	102	188	140 - 275	23	207	150 - 275	0.23
Traun	Wild	*S.trutta*	34	195	120 - 255	4	225	195 - 255	0.12
Traun	Wild	*S.cephalus*	584	330	105 - 600	30	256	160 - 375	0.05
Traun	Wild	*T.thymallus*	109	261	115 - 410	34	269	125 - 405	0.31
Traun	Stocked	*O.mykiss*	3,279	326	265 - 530	239	312	265 - 430	0.07
Traun	Stocked	*S.trutta*	272	364	260 - 430	8	372	350 - 415	0.03
Traun	Unknown	*O.mykiss*	10	188	135 - 250	1	-	-	0.10
Traun	Unknown	*S.trutta*	34	195	120 - 255	4	-	-	0.12
Alm	Wild	*O.mykiss*	487	251	135 - 540	54	217	145 - 255	0.11
Alm	Wild	*S.trutta*	290	263	130 - 525	35	212	140 - 255	0.12
Alm	Wild	*S.cephalus*	1	280	-	0	-	-	0.00
Alm	Wild	*T.thymallus*	40	302	140 - 400	13	307	275 - 320	0.33
Alm	Stocked	*O.mykiss*	876	324	260 - 470	41	336	336 - 336	0.05
Alm	Stocked	*S.trutta*	411	333	280 - 368	61	333	285 - 368	0.15
Alm	Unknown	Trout	462	250	135 - 540	56	308	260 - 390	0.12
Ager	Wild	*B.barbus*	87	467	160 - 670	9	374	290 - 410	0.10
Ager	Wild	*O.mykiss*	22	451	210 - 380	1	320	-	0.05
Ager	Wild	*P.fluviatilis*	1	130	-	0	-	-	0.00
Ager	Wild	*S.trutta*	4	295	220 - 415	0	-	-	0.00
Ager	Wild	*S.cephalusP*	189	170	135 - 535	13	292	225 - 365	0.07
Ager	Wild	*T.thymallus*	98	188	140 - 450	20	310	165 - 370	0.20
Ager	Stocked	*O.mykiss*	540	294	284 - 305	38	291	284 - 305	0.07
Ager	Unknown	*O.mykiss*	17	290	210 - 380	1	320	-	0.06

Goosander *(Mergus merganser)*

Upper Austria is home to the most important occurrence of the goosander nationwide – around 30 % of the Austrian stock live here (Weißmeier et al., 2011). The repopulation process began at the Salzkammergut lakes at the end of the 1970s and in the Traun valley in 1987. The preferred small, slender prey fish is between 10 cm and 15 cm, sometimes up to 30 cm long, and hunted in a river depth of < 2 m (von Blotzheim, 1992; Weißmeier et al., 2011). The birds are not specialized in catching salmonids but eat the most abundant and easily accessible fish. The daily food requirement of adult goosanders is estimated at 240 – 522 g (Rudolph, 1997). The development of the *M. merganser* population is shown in Figure 13. The number of midwinter individuals occurring in the region is fluctuating from year to year, but the trend shows a slight increase in the number of *M. merganser*.

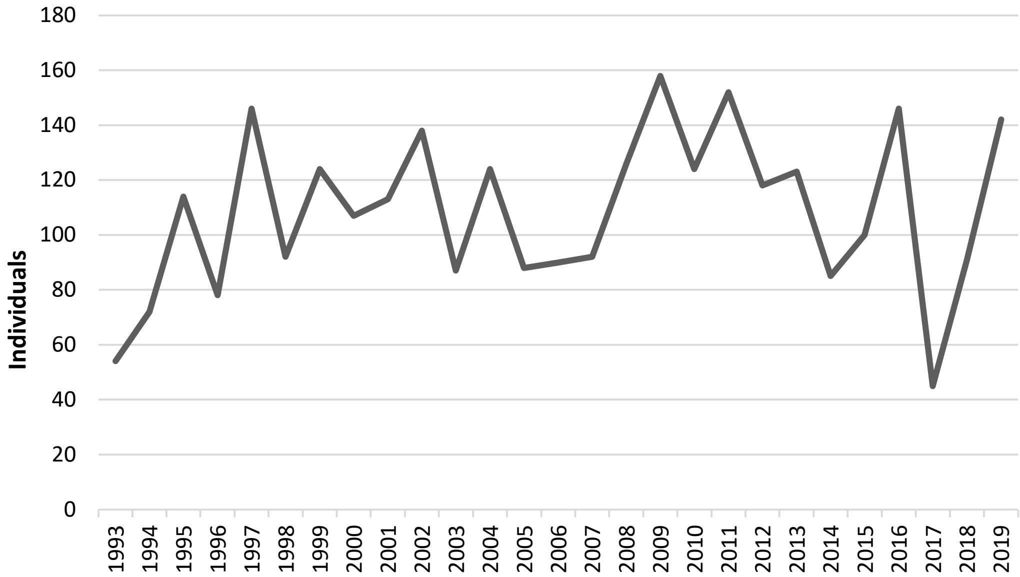

Figure 13: Number of goosanders at River Traun and tributaries during the midwinter waterfowl censuses from 1993 to 2019 (based on Weißmeier, 2018).

5.2 Historical development of fish stocks and species composition

Human alterations addressed in chapter 5.1 affect species number and composition, abundance, and biomass of rivers. To assess these effects, analysis of the change in the metrics over time using existing quantitative data from fish stock surveys is necessary. Finally, selected representatives of salmonid, cyprinid, and other families are subjected to historical occurrence and distribution, and stock development over the last three to four decades.

5.2.1 Historic fish species assemblage of River Traun and its temporal change

Research of historical records by Haidvogl and Waidbacher (1997) revealed 26[3] fish species occurring in River Traun in pristine conditions in times with little or no human influence. In recent years, *S. trutta* and *S. trutta lacustris* are considered one species with different life forms but are distinguished in the following to address the two life forms separately. In the River Traun, a general trend towards more species is recently observed in both sections up- and downstream of TF when comparing the historical information (1463 to 1959) and recent records from fish stock surveys since 1992 (Table 5). *A. bipunctatus, B. barbatula*, *B. bjoerkna*, *C. elongatoides, E. mariae,* and *S. erythrophthalmus* could no longer be verified with the latest fish stock surveys between LT and TF. Recent surveys further indicate the establishment of nine formerly non-existing species: *A. aspius, H. hucho, A. anguilla, L. gibbosus, C. carpio, P. semilunaris, G. cernua, S. fontinalis,* and *O. mykiss*. In the stretch downstream of TF, *A. aspius* and *Z. zingel* are missing, but 22 new species occur in the Lower Traun, which were not described in historical sources before (Table 5). Twelve of these species did not belong to the reference fish species assemblage and were introduced by mistake (Gobiidae, Cyprinidae) or intention (e.g., *O. mykiss*, *S. fontinalis*). The dominant species *L. lota* is proven in the Lower Traun, but the evidence is based on a small number of captured specimens during recent fish stock surveys.

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[3] *Abramis brama, Alburnus alburnus, Alburnus mento, Aspius aspius, Barbatula barbatula, Barbus barbus, Chondrostoma nasus, Coregonus sp., Cottus gobio, Cyprinus carpio, Esox Lucius, Eudontomyzon mariae, Gobio gobio, Hucho hucho, Leuciscus idus, Leuciscus leuciscus, Lota lota, Phoxinus phoxinus, Rutilus meidingeri, Salmo trutta, Salmo trutta lacustris, Squalius cephalus, Telestes souffia, Thymallus thymallus, Tinca tinca, Zingel streber, Zingel zingel*

Table 5: Reference condition (dominant (d), subdominant (s) and rare (r) species after Haunschmid et al., (2017), historic (1463 to 1959) and recent (1992 to 2019) occurring species in River Traun. Successfully identified species that are not included in the reference condition are listed in the lower part of the table.

		LT (incl.) - TF				TF - Danube			
Family	***Scientific name***	Ref.[1]	1463-1959[3]	1992-2019	Change	Ref.[2]	1463-1959[3]	1992-2019	Change
Acipenseridae	*Acipenser ruthenus*					r			
Cobitidae	*Barbatula barbatula*	s	1		-	s		1	+
	Cobitis elongatoides		1		-	r			
	Misgurnus fossilis					r			
Cottidae	*Cottus gobio*	d	1	1		s	1	1	
Cyprinidae	*Abramis brama*	r	1	1		s		1	+
	Alburnoides bipunctatus	s	1		-	r	1	1	
	Alburnus alburnus		1	1		s	1	1	
	Alburnus mento	r	1	1		r		1	+
	Aspius aspius			1	+	r	1		-
	Barbus barbus	s	1	1		d	1	1	
	Carassius Carassius					r			
	Chondrostoma nasus					d	1	1	
	Gobio gobio	s				s	1	1	
	Leuciscus idus					s			
	Leuciscus leuciscus	s				s	1	1	
	Rhodeus amarus					r			
	Phoxinus phoxinus	d	1	1		s	1	1	
	Rutilus meidingeri	r	1	1		r		1	+
	Rutilus rutilus	r	1	1		s		1	+
	Rutilus pigus					r			
	Scardinius erythrophthalmus		1		-	r		1	+
	Squalius cephalus	s	1	1		s	1	1	
	*Telestes souffia**		1*		-*	r	1*	1	+*
	Tinca tinca	r	1	1		r		1	+
	Vimba vimba	r	1	1		r			
Esocidae	*Esox Lucius*	s	1	1		s	1	1	
Gadidae	*Lota lota*	d	1	1		s	1	1	

Percidae	*Gymnocephalus cernua*			1	+	r		1	+
	Perca fluviatilis	s	1	1		s		1	+
	Sander lucioperca		1	1		r		1	+
	Zingel streber					r			
	Zingel zingel					r	1		-
Petromyzontidae	*Eudontomyzon mariae*	r	1		-	r			
Salmonidae	*Coregonus sp.*	r	1	1					
	Hucho hucho			1	+	s	1	1	
	Salmo trutta	d	1	1		s	1	1	
	Salmo trutta lacustris	s	1	1		r		1	+
	Thymallus thymallus	d	1	1		d	1	1	
Siluridae	*Silurus glanis*					r		1	+
Anguillidae	*Anguilla Anguilla*			1	+			1	+
Centrarchidae	*Lepomis gibbosus*			1	+				
Cyprinidae	*Blicca bjoerkna*		1		-				
	Carassius auratus							1	+
	Carassius gibelio							1	+
	Cyprinus carpio			1	+			1	+
	Gasterosteus aculeatus							1	+
	Pseudorasbora parva							1	+
Gobiidae	*Neogobius melanostomus*							1	+
	Proterorhinus seminularis			1	+			1	+
Salmonidae	*Salvelinus fontinalis*			1	+		1	1	
	Salvelinus umbla		1	1					
	Oncorhynchus mykiss			1	+			1	+
Total	53	22	26 (27*)	29		39	17 (18*)	37	
New species					9				21 (22*)
Vanished species					6 (7*)				2

[1] (Gassner et al., 2003; Pesendorfer & Schützinger, 1994)
[2] (Kainz, 1992)
[3] (Borne, 1880; Fitzinger, 1879; Haidvogl & Waidbacher, 1997; Heckel & Kner, 1858; Kerschner, 1956; Kukula, 1874; Scheiber, 1930; Wacha, 1956; Wittmack, 1875)
* no specific distribution indicated (Kukula, 1874)

5.2.2 Traun: Development of abundance and biomass over the last 40 years

Fish stock surveys from the last four decades are integrated into the following figures to show the impacts on the fish fauna. In total, 51 electrofishing surveys from 1985 to 2019, listed in Table 15 of the appendix, are merged in Figure 14 (abundance) and 53 in Figure 15 (biomass). In addition, the boxplots in this chapter and chapters 5.2.4 & 5.2.6 show the stock surveys for each fish region over time, allowing better visualization of the development in abundance, biomass, and species numbers in the last three to four decades.

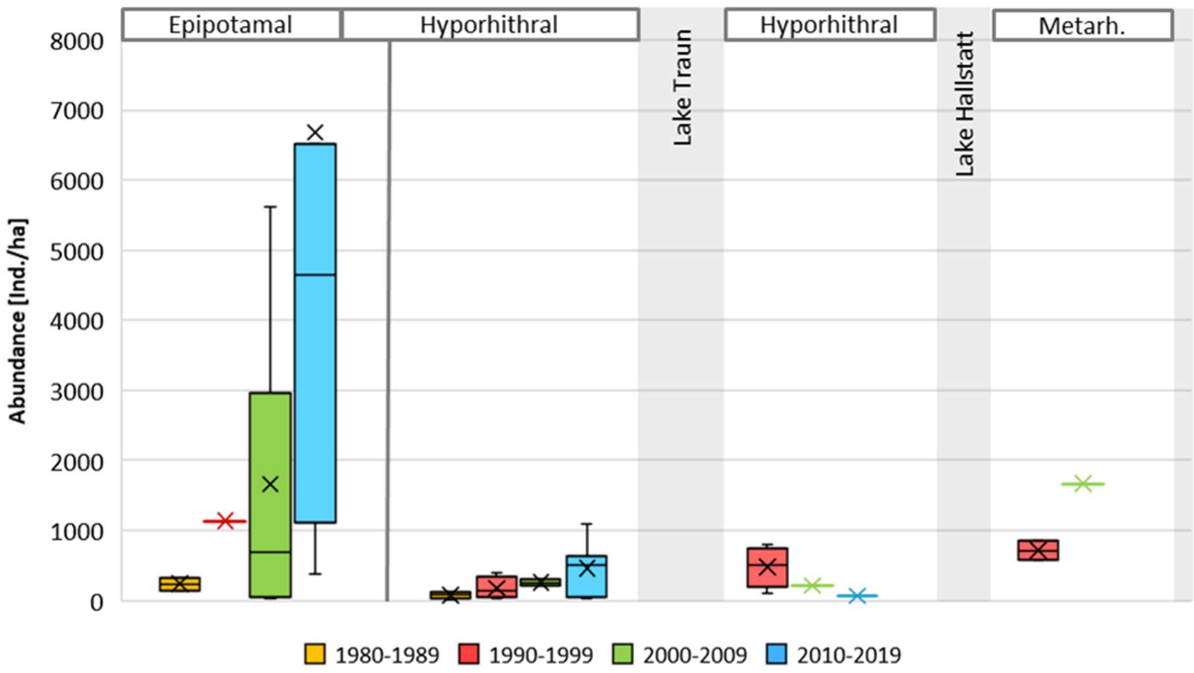


Figure 14: Abundance boxplots [Ind/ha] of fish stock assessments in the longitudinal course of the River Traun; separated by fish regions and decades. Two stock surveys with abundance of 15,628 and 27,337 Ind/ha (2010 – 2019) at river-km 6.2 and 6.75 are removed due to the extreme axis distortion.

In Figure 14, a trend towards higher abundance for consecutive decades is observed downstream of LT. In the middle and upper reach of River Traun, the abundance is only a fraction compared to the values from the epipotamal in the last 20 years. No recent fish stock assessment is available in the upper reach. In the 1980s, the maximum abundance was 329 Ind/ha; however, the focus was on the analysis of stock-forming species, so small fish species (e.g., *A. bipunctatus; C. gobio*; *P. phoxinus*), who largely contribute to the total abundance, were not calculated and therefore underestimated in the assessments. The temporal species composition and the detailed development of the abundance are addressed in chapters 5.2.3 & 5.2.4.

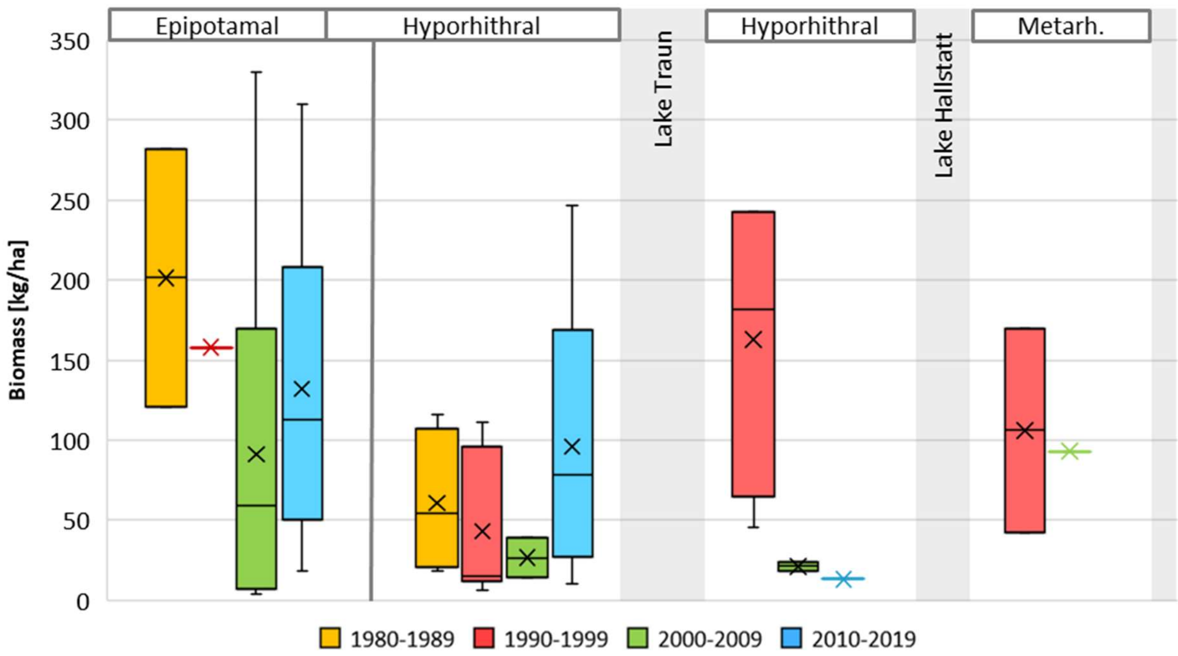


Figure 15: Biomass boxplots [kg/ha] of fish stock assessments in the longitudinal course of the River Traun; separated by fish regions and decades.

The biomasses of past fish stock surveys in the Traun catchment are shown in Figure 15. In the epipotamal and hyporhithral of the Lower Traun, the biomass decreases from 1980 to 2009 but increasing ever since. In the middle reach, the biomass has lowered dramatically since the 1990s. In this period, biomasses to 240 kg/ha were verified, and the last survey in the recent decade resulted in 13 kg/ha biomass. Besides extrema higher than 330 kg/ha close to the estuary in the last 20 years, the average biomass is usually below 100 kg/ha in all sections but the epipotamal. The biomass in the most recent decade varies widely between 18 and 310 kg/ha downstream of TF and from 10 to 246 kg/ha upstream of TF. The detailed fish family and species compositions in the longitudinal and temporal course are shown in the following chapters.

5.2.3 Traun: Changing species composition over the last 40 years

In alpine rivers, the number of **species** increases from metarhithral (trout region) to hyporhithral (grayling region) and epipotamal (barbel region). Few, cold water preferring species like *S. trutta* and *C. gobio* characterize the upper reaches. In the hyporhithral (grayling region), *T. thymallus* is naturally the most abundant species, but cyprinid species also occur to a certain extent. In the epipotamal, Salmonidae usually are subordinate and are substituted by cyprinids as the dominant family, with *B. barbus* being the most common species. As indicated in Figure 17, the number of species is increasing in every stretch from the estuary to the upper reach compared to 1980 until 1999 (see also Figure 53 in the appendix). The species number decreases from the river mouth to the headwaters in the 1980s, with one exception where fewer species were observed in the epipotamal than in the hyporhithral. This finding does not correspond to the natural distribution. On average, 14 to 15 fish species occur from TF to the Danube from 1990 to 2019. Upstream of TF to LT, an overall increase from 8 (1980s), to 12 (2000s), and 10 (2010s) is observed. Upstream of LT, the species number increases from 7 (1990s) to 9 (2010s).

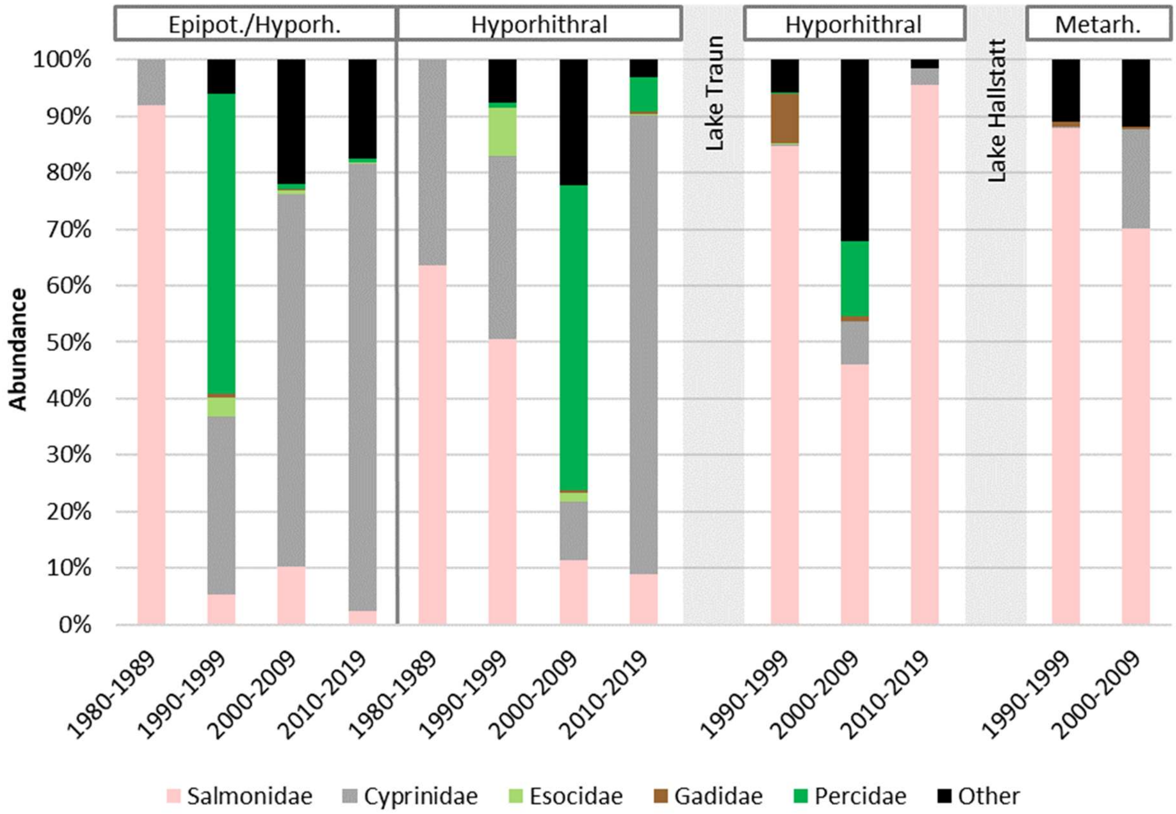


Figure 16: Development of fish family composition in the total abundance in the longitudinal course of the River Traun; separated by fish regions and decades; "Other" are Anguillidae, Cobitidae, Cottidae, Gobiidae, Siluridae.

The share of fish families in the total **abundance** is displayed in Figure 16. The salmonid density decreased significantly from > 90 % to < 5 % in the Lower Traun within 40 years. Between TF and LT, the same trend is observed as the share dropped from almost 65 % in the 1980s to < 10% in the last ten years. Upstream of LT, the share also decreased from ~ 85 % (1990 to 1999) to ~ 45 % in the next decade but recovered to > 95 % in the 2010s. As shown in Figure 17, the salmonid family consisted mainly of *O. mykiss* (57 %) and *T. thymallus* (35 %)

downstream of TF in the 1980s; *B. barbus* accounted for the remaining 8 %. In the following decade, *P. fluviatilis* was the dominant species with a share of 53 %, followed by *S. cephalus* with 21 %. From 2000 to 2009, the fish densities were more evenly distributed, led by *P. phoxinus* (34 %), *S. cephalus* (17 %), *C. gobio,* and other species (14 % each). In the 1990s, salmonid abundance upstream of LT consisted of 47 % of *S. trutta* and 34 % of *T. thymallus*. *O. mykiss* occurs to a small proportion of 2 %. From 2000 to 2009, the share of *S. trutta* decreased to 17 % and once again to 5 % in the following decade. A similar development is seen for *T. thymallus* (6 % from 2000 to 2009), although the species recovered slightly to 17 % between 2010 and 2019. In contrast, *O. mykiss* raised its share from 2 % to 22 % in the 2000s and again to 73 % in the recent decade. The Gadidae (*L. lota*) has almost disappeared in the Lower and Middle Traun in recent times. In the 1990s, the share in the total abundance was > 13 % upstream of LT but is steadily decreasing ever since. In the last 20 years, 20 individuals of *L. lota* were recorded in fish stock surveys, of which six specimens were detected within the last ten years.

Salmonid abundance is substituted largely by the cyprinid family, forming a share of > 80 % between 2010 and 2019 in both sections between Danube and LT. The species with the highest densities in this period are *P. phoxinus* (42 %) and *A. bipunctatus* (20 %) downstream of TF, and *S. cephalus* (34 %) and *B. barbus* (23 %) upstream of TF. In the middle and upper reach of the river, cyprinids are rarely found in the last 40 years.

The Gadidae (*L. lota*) has almost disappeared in the Lower and Middle Traun in the last decades. In the 1990s, the share in abundance was > 13 % upstream of LT but steadily decreased ever since.

Represented by P. fluviatilis, the percid family forms proportions of > 50 % of the total abundance, for instance, downstream of TF in the 1990s and upstream of TF in the 2000s. In the middle reach, *P. fluviatilis* has a share of 13 % of the total abundance between 2000 and 2009.

Other families (e.g., Anguillidae, Cobitidae, Cottidae, Gobiidae, Siluridae) show shares between 2 % and 22 % downstream of LT and 32 % in the middle and upper reach from 2000 to 2009. The lowest value is recorded in the hyporhithral between the lakes in the recent decade.

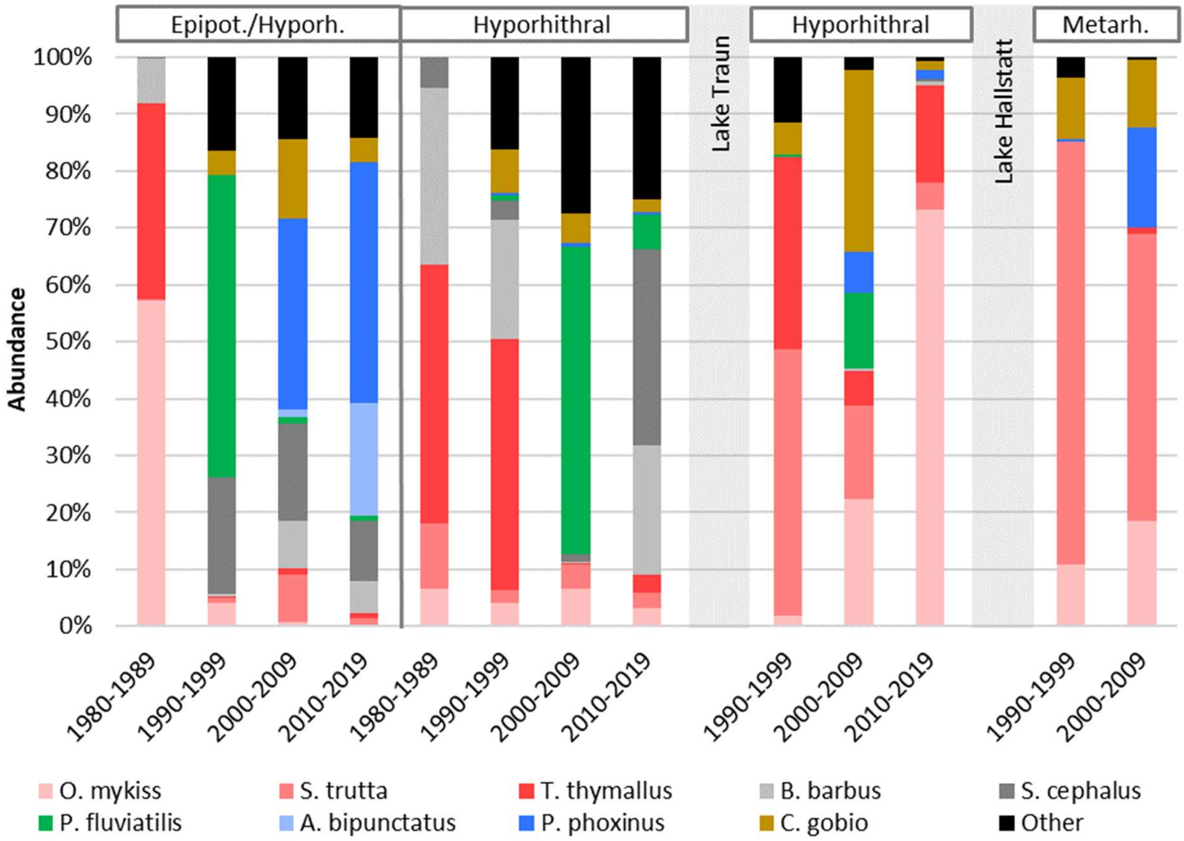


Figure 17: Development of fish species composition in the total abundance in the longitudinal course of the River Traun; separated by fish regions and decades; Other species are listed in Table 12 (Appendix).

The development of the biomass-related fish family composition in the longitudinal course of the River Traun is shown in Figure 18. The salmonid family showed a 90 % biomass dominance in the 1980s downstream of TF, consisting of 65 % of *O. mykiss* and 26 % of *T. thymallus* (Figure 19). In the 1990s, the salmonid share dropped dramatically to 10 %, of which rainbow trout accounted for 9 % and grayling for 1 %. The salmonid share then increased slightly over the next two decades but remained below 15 % in the recent decade. From TF to LT, the biomass share was stable at 50 to 55 % between 1980 and 2009 and fell to < 10 % in the recent decade. Until 1999, *T. thymallus* had a proportion of 36 % and 47 % but decreased sharply to < 3 % in the following two decades. Thus, in the middle reach of River Traun, the salmonid family forms 80 to 90 % of the biomass throughout the last 30 years. On the other hand, *O. mykiss* shares in the total biomass steadily increase from 2 % (1990s) to 47 % (2000s) and 67 % (2010s). The same development applies for the metarhithral, but with total salmonid shares above 90 %, consisting to 23 % - 32 % of *O. mykiss* and 68 % - 53 % of *S. trutta* in the 1990s and the 2000s, respectively.

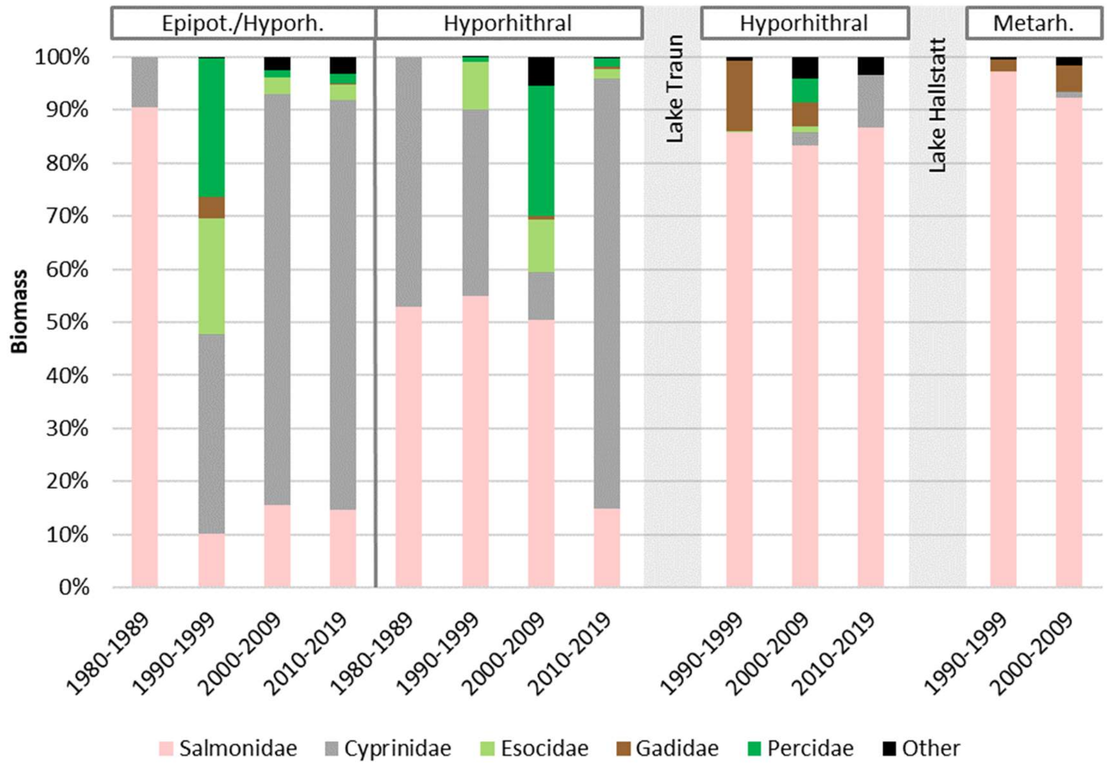


Figure 18: Development of fish family composition in the total biomass in the longitudinal course of the River Traun; separated by fish regions and decades; "Other" are Anguillidae, Cobitidae, Cottidae, Gobiidae, Siluridae.

Cyprinid species downstream of TF had a proportion of 9 % in the 1980s' biomass (mainly *B. barbus*), increasing to > 35 % in the 1990s (mainly *S. cephalus*) before becoming the dominant fish family with a share of ~ 75 % in the following decades. Most dominant between 2000 and 2019 are *S. cephalus* (42 % - 41 %) and *B. barbus* (28 % - 26 %). Except for the confluence with the Danube, the *C. nasus* s missing in the Lower Traun. Upstream of TF, the biomass consisted of cyprinids to the extent of about 45 % (1980 to 1989) and 35 % (1990 to 1999). In the next decade, cyprinids dropped to < 10 % before becoming the dominant family with a proportion of 80 % in the last ten years. Unlike in the epipotamal, *B. barbus* takes over the biomass dominance with proportions of 39 % (1980s), 26 % (1990s), 2 % (2000s), and 63 % (2010s). *S. cephalus* contributes up to the extent of 17 % in the recent decade. In the hypo- and metarhithral upstream of LT and LH, Cyprinidae show subordinate shares of the total biomass throughout the last 40 years, but the biomass consists of 10 % of cyprinid species in the middle reach during recent investigations.

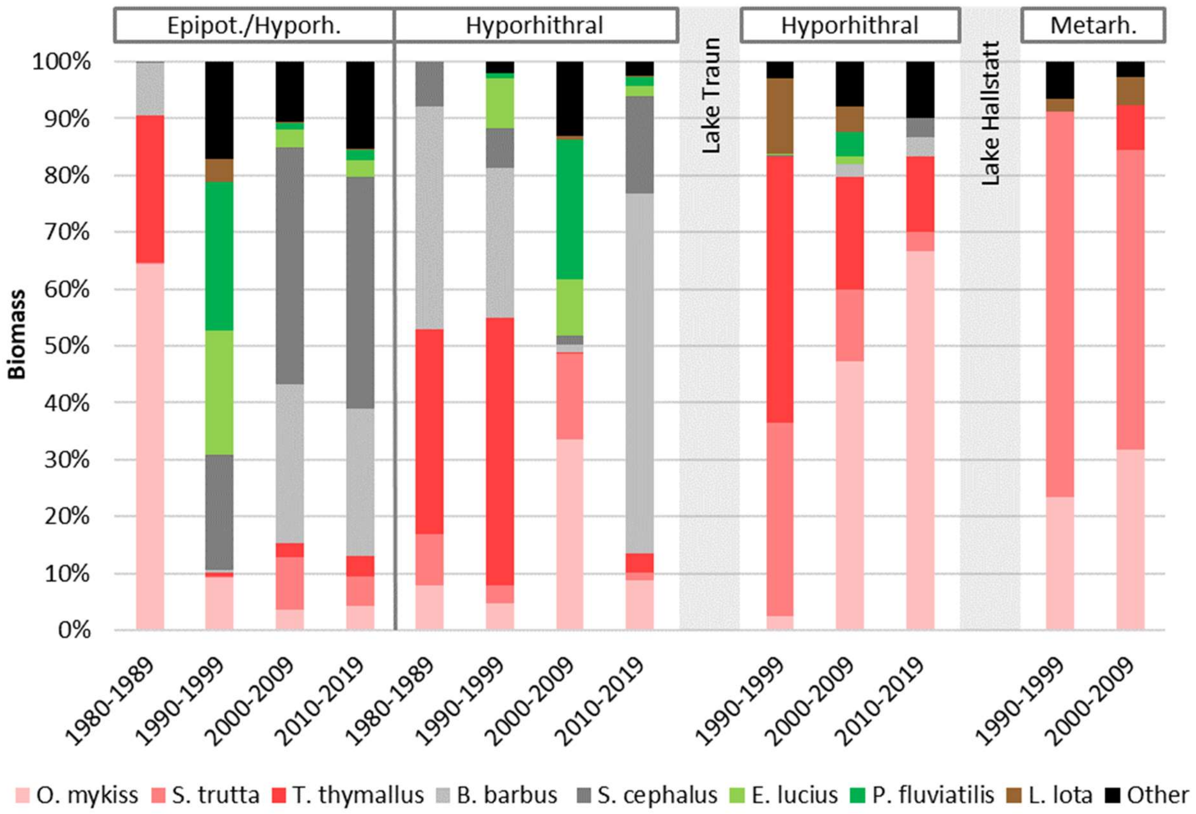


Figure 19: Development of fish family composition in the total biomass in the longitudinal course of the River Traun; separated by fish regions and decades; Other families are listed in Table 12 (Appendix).

E. lucius (Esocidae) contributes to 22 % of the biomass in the 1990s from the Danube to TF. However, the share declines to < 5 % downstream of TF in the following two decades. While *E. lucius* was not documented in the 1980s, the share stabilized at ~ 10 % in the next two decades. Since 2010, the species occurs in negligible biomasses up- and downstream of LT.

The reference species *L. lota* had a share of 13 % in the middle reaches in the 1990s, but the proportions have been declining ever since. In the metarhithral, the biomass share of *L. lota* is below 5 % from 1990 to 2009.

Percidae account for ~ 25 % of the biomass in the 1990s (downstream of TF) and the 2000s (upstream of TF). The shares are below 5 % in all other decades.

A closer examination of fish species reveals that “other“ species contribute to 17 % (1990 to 1999) and 15 % (2010 to 2019) to the biomass from Danube to TF. Upstream, a share of 13 % is reached between 2000 and 2009.

5.2.4 Alm: Development of abundance and biomass over the last 40 years

At the River Alm, nine electrofishing surveys, carried out between 1980 and 2019 (river-km 0.5 to 32.5), are visualized in Figure 20. A listing of the stock surveys is provided in Table 15 of the appendix.

The average abundance is approximately at the same level from 1980 to 2019, with a median ~ 700 Ind/ha. In the 2000s, the range and the average density of ~ 850 Ind/ha are the highest compared to the other decades. The only fish stock survey in the recent decade resulted in 744 Ind/ha.

The mean biomass in the 1980s is 62 kg/ha, before decreasing to 27 kg/ha in the following decade and ultimately reaching 35 kg/ha in the 2010s. Between 2000 and 2009, the broadest interquartile range from ~ 10 to 45 kg/ha and the maximum biomass of 77 kg/ha at river-km 19,5 is proven, linked to stocking when considering the length-frequency diagram of brown trout in the stock analysis.

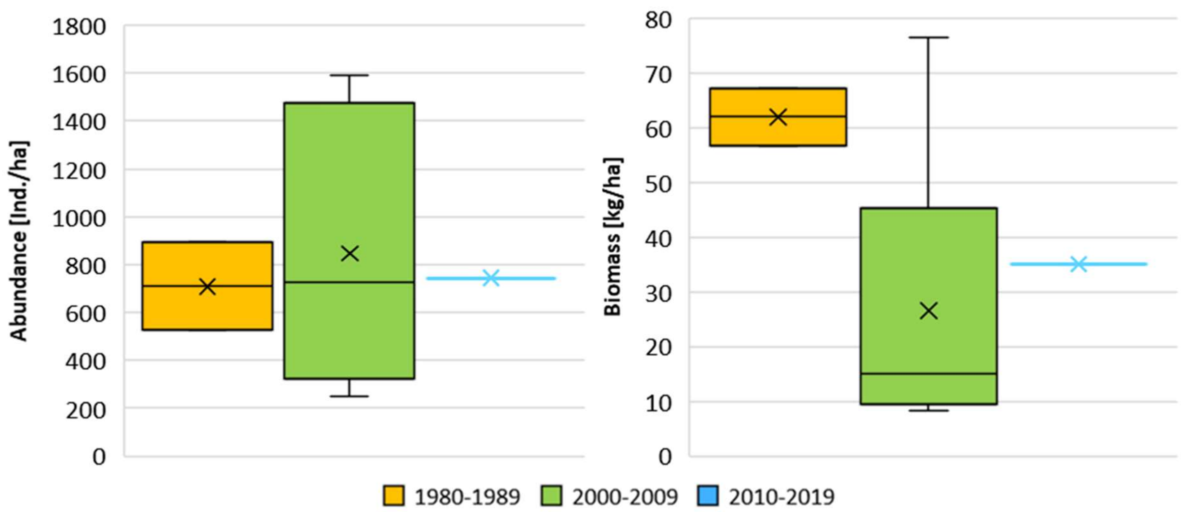


Figure 20: Abundance [Ind/ha] and biomass [kg/ha] boxplots of fish stock assessments in the temporal course of the River Alm; separated by decades.

5.2.5 Alm: Changing species composition over the last 40 years

The species number shows a steady upward trend at the River Alm. The number increased from 3 in the 1980s to 4.5 in the 2000s and finally to 8 in the recent assessment period (Appendix Figure 54).

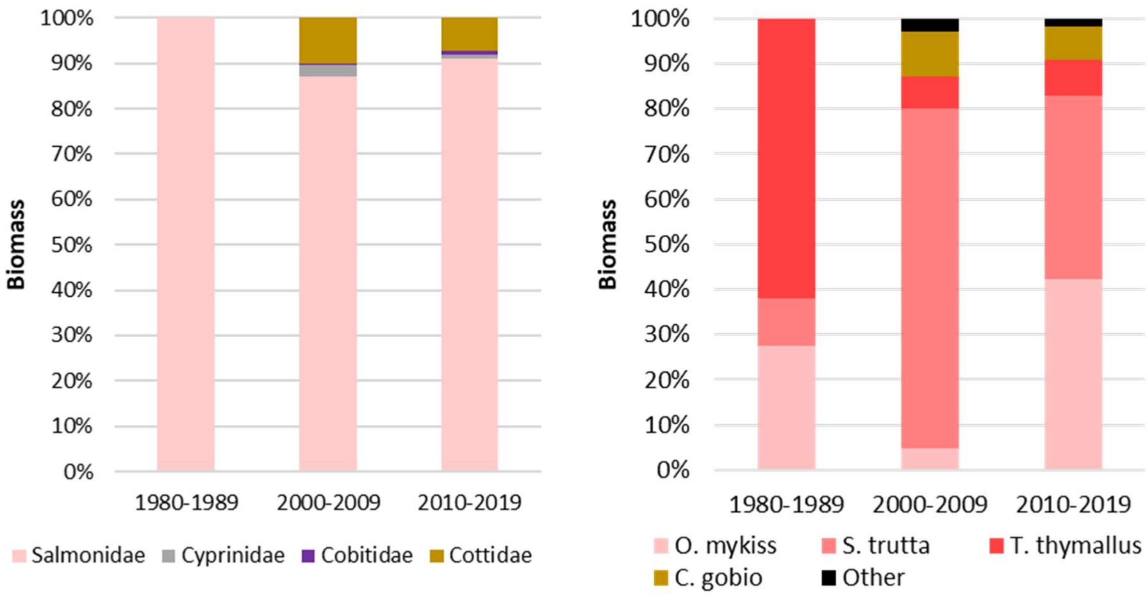


Figure 21: Development of fish family and species composition in the total biomass of the River Alm; separated by decades; "Other" species are listed in Table 12 (Appendix).

The proportions of fish families and species in the total biomass are displayed in Figure 21. Salmonidae dominate accompanied by *C. gobio* to the extent of < 10 %. The share of salmonids is 100 % in the 1980s, consisting of 28 % of *O. mykiss*, 10 % of *S. trutta*, and 62 % of *T. thymallus*. The sampling at that time did not focus on smaller accompanying species, which explains the high salmonid share. However, the salmonid share dropped to 87 % between 2000 and 2009. *S. trutta* took over the dominance (75 %) from dwindling *T. thymallus* (7 %) and *O. mykiss* (5 %). From 2010 to 2019, the predominance shifted again; this time *O. mykiss* is the beneficiary with 42 % of the total biomass, followed by *S. trutta* (41 %), *T. thymallus* (8 %), and *C. gobio* (7 %).

Cyprinid species occur in the Alm with single specimens and contribute only to a minor extent to the fish abundance and biomass.

5.2.6 Ager: Development of abundance and biomass over the last 30 years

Twenty-six electrofishing surveys from 1990 to 2019 at the Ager are merged in Figure 22, listed in Table 15 of the appendix.

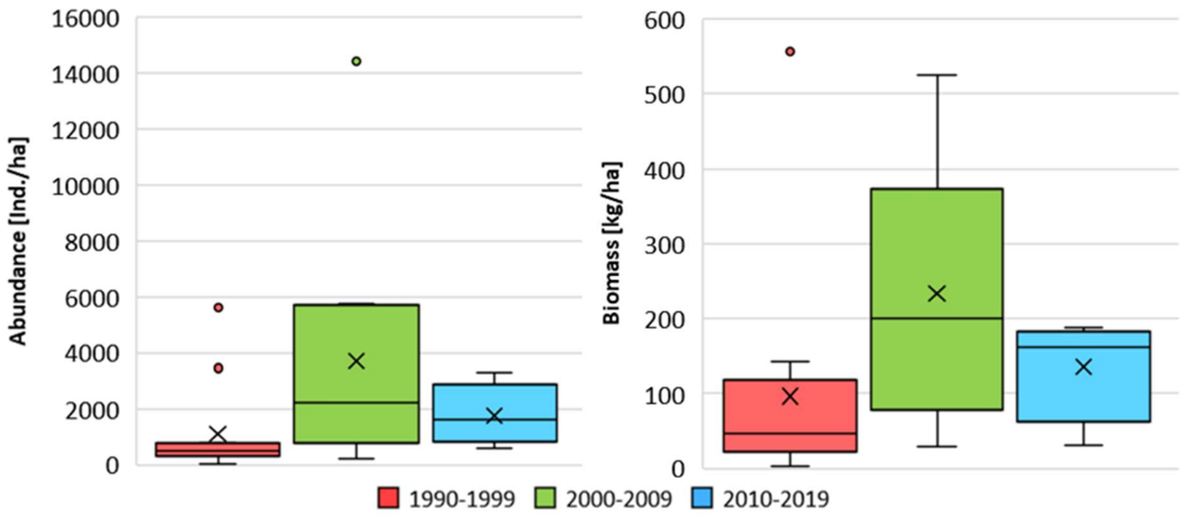


Figure 22: Abundance [Ind/ha] and biomass [kg/ha] boxplots of fish stock assessments in the temporal course of the River Ager; separated by decades.

The fish abundance in the River Ager is relatively high but did not increase in the last decade compared to River Traun. The highest abundance is recorded between 2000 and 2009, with an average density of 3,717 Ind/ha. In the 1990s, the abundance averages 1,087 Ind/ha. In 2008, an extraordinarily high abundance of 14,430 Ind/ha was assessed at river-km 21.1, consisting mainly of *B. barbus* and *S. cephalus*. In the recent decade, between 576 and 3,287 Ind/ha, and on average 1,760 Ind/ha, were attained.

The biomass at the River Ager has fluctuated remarkably throughout the last 30 years. The lowest value is recorded in the 1990s (5 kg/ha) the highest in the 2000s (525 kg/ha). The mean biomass from 1990 to 1999 is 96 kg/ha. The outlier of 556 kg/ha is recorded in 1994, of which 92 % is formed by *B. barbus* (70 %) and *S. cephalus* (22 %). In the 2000s, the interquartile range is the widest, with the average also being the highest (234 kg/ha). From 2010 to 2019, three out of four fish stock surveys are performed closer than 2 km to the estuary. The average biomass is 135 kg/ha. In 58 % of the 26 assessments, 50 kg/ha was surpassed, while eleven failed. The detailed fish family and species compositions in the temporal course are shown in the next chapter.

5.2.7 Ager: Changing species composition over the last 30 years

In River Ager, the mean species numbers increased in each decade of the last 30 years from 6.7 (1990s) to 7.4 (2000s) and 10.3 (2010s) (Appendix Figure 54). Maximal 13 species are evidenced in the 2019 fish sampling campaign close to the estuary .

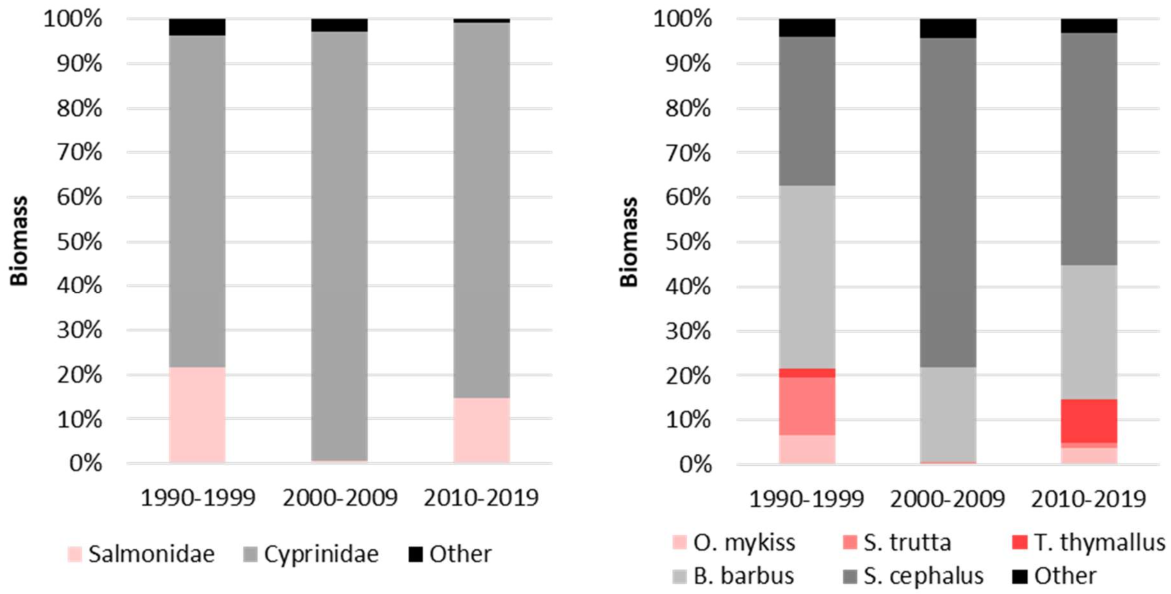


Figure 23: Development of fish family and species composition in the total biomass of the River Ager; separated by decades; "Other" families are Anguillidae, Cobitidae, Cottidae, Esocidae, Gobiidae, Percidae, Siluridae; "Other" species are listed in Table 12 (Appendix).

The shares of fish families and species in the total biomass of the Ager are shown in Figure 23. Salmonidae exhibit a subordinate share in the total biomass in the last 30 years. In the 1990s, 22 % of the biomass were salmonids, consisting of 6 % of *O. mykiss*, 13 % of *S. trutta*, and 2 % of *T. thymallus*. The overall share dropped to 1 % the following decade before recovering to 15 % in the 2010s, consisting of 10 % *T. thymallus*, 4 % *O. mykiss*, and 1 % *S. trutta*. Cyprinidae are the dominant fish family in the River Ager and contribute to 75 % (1990s), 96 % (2000s), and 84 % (2010s) to the total biomass. *B. barbus* (21 - 41 %) and *S. cephalus* (33 - 74 %) have the most significant shares in the investigated periods. Other families and species contribute to < 4 % of the total biomass.

5.2.8 Historical development of selected species

In the following chapters, historic information was gathered to describe the occurrence, importance, and development of selected key species in the rivers Traun, Alm, and Ager. The selection includes all representatives of the salmonid family, two small cyprinid species, and three large cyprinid species.

5.2.8.1 *Hucho hucho* (Linnaeus, 1758)

The huchen or Danube salmon (*H. hucho*) was first mentioned in 1418 in the Lower Traun (Scheiber, 1930). Before 1777 the species had a minimum harvest length of 35 cm (~0.4 kg) before it changed to 65 cm in the 20th century (Haidvogl & Winiwarter, 2016; Kerschner, 1956). The species occurred in the Lower Traun up to its natural distribution limit of TF in healthy populations throughout the year and also migrated into the tributaries Ager and Alm during spawning season in April and May (Heckel, 1851; Kerschner, 1956; Kukula, 1874; Ratschan & Zauner, 2012). The fish markets of Linz and Vienna were supplied with the commercially important species from the Rivers Traun and Ager (Haidvogl & Winiwarter, 2016; Kerschner, 1956; Ratschan & Zauner, 2012). However, the huchen stock decreased noticeably at the end of the 19th and 20th centuries. Reportedly, only six individuals were captured by a local fisherman in the Ager in 1923 (Kerschner 1956; Haidvogl and Winiwarter 2016; Wohlschlager, 2002). The autochthonous occurrence of huchen in rivers Traun and Ager began to decrease and ultimately extinct in the following years (Spindler & Chovanec, 1997).

Since the 1950s, huchen stocks have been under pressure and declining sharply because of increasing water pollution, clogging of the spawning substrate, hydro-engineering measures, and missing accessibility of their spawning grounds in the tributaries (chapter 5.1). The species is nationally protected and listed in annexes II and V of the Austrian "Flora-Fauna-Habitat Guideline" (Umweltbundesamt, 2019). However, the water quality of many former spawning areas of the Huchen has been restored to such an extent that recovery projects are promising.

In the last 20 years, only individual findings of huchen are documented for the Lower Traun (Figure 24). The last 0+ huchen was identified near Lambach in 2005. The remaining evidence was obtained almost exclusively from adult specimens, one finding is proven outside their natural distribution range upstream of TF, but the majority are identified in the relatively narrow range of river-km 49 and 71. According to the local fishery managers, stocking takes place at irregular intervals. In River Ager, the only specimen of *H. hucho* in the last 30 years was identified during the 2019 sampling campaign.

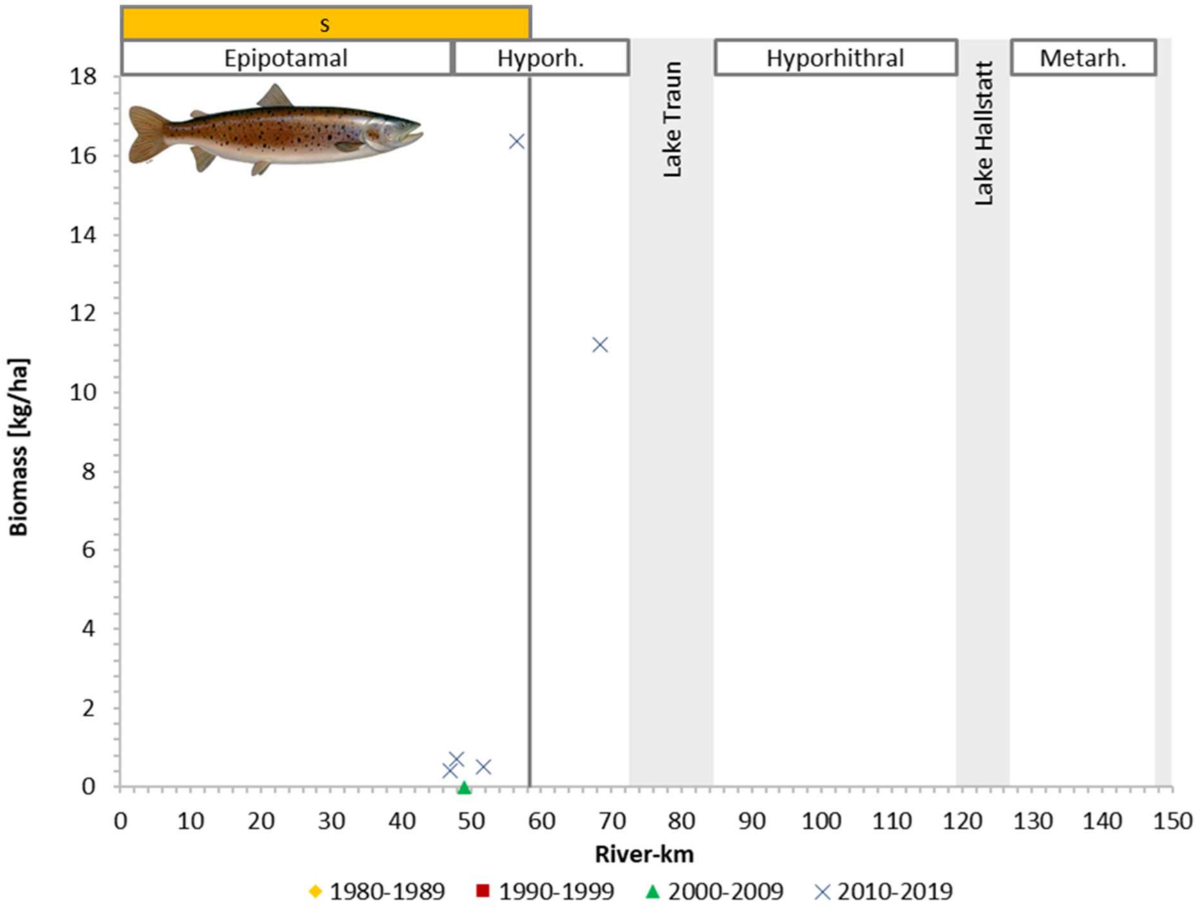


Figure 24: Longitudinal and temporal course of H. hucho biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

5.2.8.2 *Salmo trutta* (Linnaeus, 1758)

Brown trout (*S. trutta*) was first mentioned in 1463. The distribution range of brown trout was the entire Traun catchment down to the estuary, where it still occurred frequently (Hufnagl & Marchetti, 1991; Kerschner, 1956; Kukula, 1874). From Gmunden to TF, specimens reached weights between 2 and 3 kg, and in the lower reaches, rich fishing grounds for brown trout were found near the city of Wels in the late 19th century (Borne, 1880). Between LH and LT Borne (1880) reported the occurrence of *S. trutta* in high abundances. The same is documented in the 1980s from Bad Ischl to LT (Kainz, 1992). Whether the information refers to the river or lake form of *S. trutta* is not specified in the historical sources.

The lake ecotype of brown trout (formerly *Salmo trutta lacustris*), in literature sources referred to as "Lachsl," was reportedly found in LH, LT, Lake Atter, and Lake Grundl from where the spawning migration into the rivers Traun and Ager started in October (Borne, 1880;

Wittmack, 1875). The stock in the Lower Traun must have been excellent at the beginning of the 19th century (Wohlschlager, 2002). The lake trout were transported and sold at the Vienna fish market around 1900 (Borne, 1880; Haidvogl & Winiwarter, 2016; Kerschner, 1956; Zauner et al., 2014). Over the following decades, anthropogenic activities changed the river's biotic and abiotic environmental conditions, leading to changes in the brown trout occurrence and biomass (chapter 5.1).

Considering the historical information, it is not clearly proven if *S. trutta* was one of the dominant species in the Lower Traun, especially downstream of TF. Bruschek (1959) reports that besides grayling and chub, mainly rainbow trout and not the native brown trout were dominant species upstream of TF. The longitudinal and temporal course data in Figure 25 certainly do not extend far enough back to reflect the historical situation. However, brown trout biomass below 10 kg/ha occurs frequently from 1985 to the present day. In the 1990s, *S. trutta* was the predominant species regarding biomass in the metarhithral and the hyporhithral upstream of Bad Ischl (~ river-km 105), where biomasses of 190 kg/ha could be detected. A fish stock survey from 2017 showed extremely low brown trout biomass in the middle reach of the Traun near Ebensee with < 1 kg/ha. Except for one individual, all caught brown trout were clearly identified as stocked animals. Downstream of LT, the *S. trutta* biomass exceeded 20 kg/ha twice since 1980, while the remaining surveys are mostly below 10 kg/ha. In general, the brown trout occurs in low biomasses and abundances in the Traun catchment, especially since 2000.

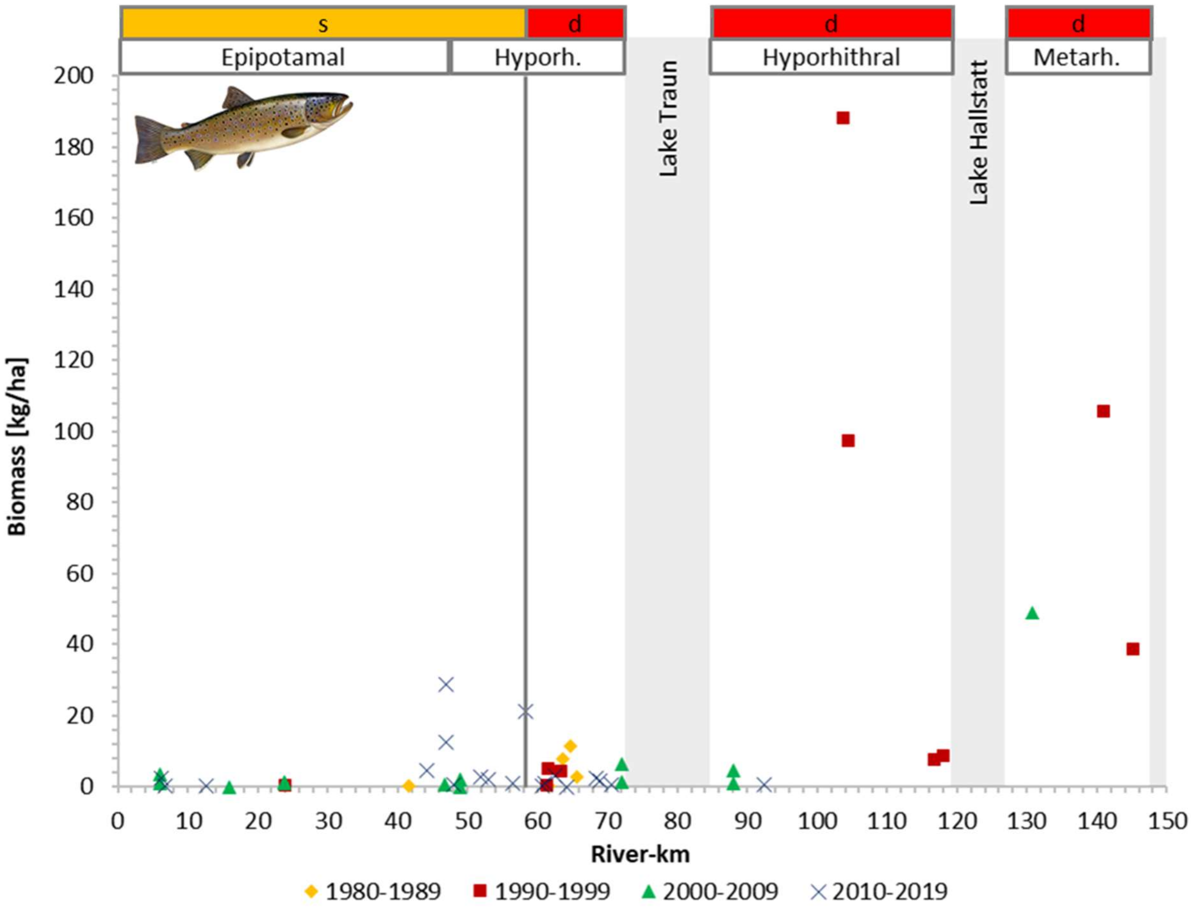


Figure 25: Longitudinal and temporal course of S. trutta biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

In the 19th century, River Alm and especially the stretch between Vorchdorf and Grünau was reportedly abundant in brown trout (Borne, 1880). The distribution range is the whole catchment up to Lake Alm, where the species was commercially captured since the mid-19th century. The reproduction of the lake population took place in the headwater streams, which were inhabited exclusively by *S. trutta* in that period (Zeitlinger, 1928).

The brown trout is proven in nine fish sampling surveys since the 1980s, reaching 1.1 and 11.8 kg/ha between 1980 and 1989 (Figure 26). Unfortunately, there are no records from the next decade available. In the 2000s, the biomass level of brown trout in River Alm is the highest with Ø 20 kg/ha, and maximally 58.1 kg/ha, which is related to stocking when considering the length-frequency diagrams of these surveys with â predominating 2+ age class, but still functioning natural reproduction.

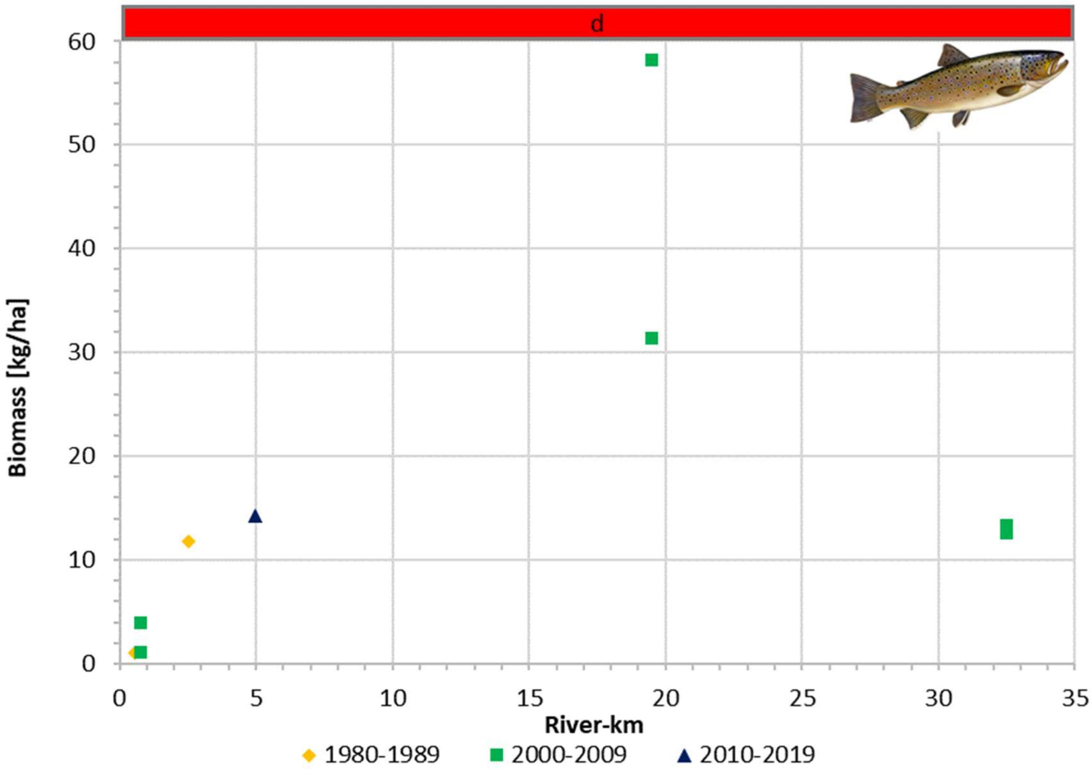


Figure 26: Longitudinal and temporal course of S. trutta biomass from past fish stock surveys under consideration of the status in the reference list in the River Alm (grouped by decades).

S. trutta is found in 21 assessments in River Ager in the last 30 years (Figure 27). From 1990 to 1999, biomasses of > 10 kg/ha have been verified in six out of eleven fish stock surveys. The average biomass in that period is 15 kg/ha, while the maximal biomass of 50 kg/ha[4] was proven in the middle reach. The biomass of *S. trutta* experienced a sharp decline in the following two decades as the species failed to exceed 2.5 kg/ha. The biomass since 2000 is extremely low compared to the 1990s.

[4] Whether this is a sign of stocking or natural production could not be determined.

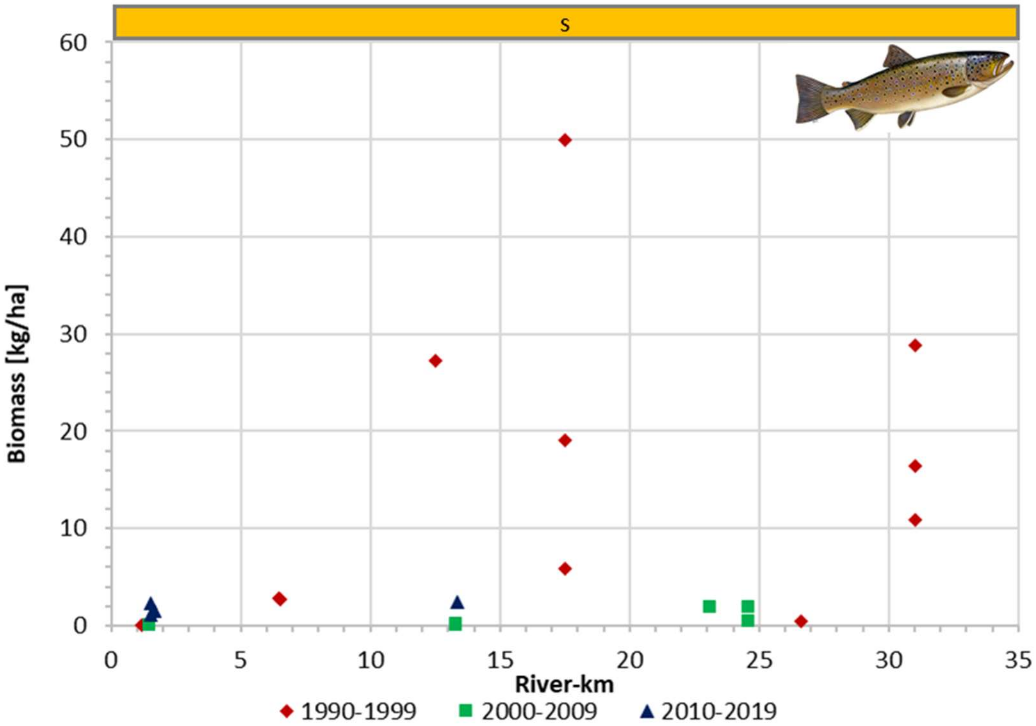


Figure 27: Longitudinal and temporal course of S. trutta biomass from past fish stock surveys under consideration of the status in the reference list in the River Ager (grouped by decades).

5.2.8.3 *Thymallus thymallus* (Linnaeus, 1758)

Grayling (*Thymallus thymallus*) was first described in 1463 in the fishing regulations of Upper Austria as a mass occurring species from the Kainischtraun to the estuary (Haidvogl & Waidbacher, 1997; Hufnagl & Marchetti, 1991). However, the existence of *T. thymallus* in the River Alm was first confirmed by Borne (1880).

T. thymallus was the economically most important species in the rivers Traun, Ager, and Vöckla since medieval times. Between 2 140 to 2 568 portions of fish were delivered by local fishermen as mandatory contributions to the Lambach Abbey yearly, emphasizing the species´ abundance in the rivers. Only the lease was earned with this amount, and the total catch was undoubtedly a multiple of this to cover the demand on the markets (Wohlschlager, 2002). The River Traun was the richest source for grayling in the country, from which a considerable amount was offered for sale at the fish market in Linz. The "Spretzlinge" and "Mailinge," i.e., young graylings, were especially appreciated despite their minimum harvest size of 30 cm, the species was intensively fished in every size class, finally leading to a stock reduction (Brachmann, 1954; Haidvogl & Waidbacher, 1997; Kerschner, 1956). At the end of the 18th century, according to records of the Abbey of Lambach's archives, the fishing water of the

Abbey was rich in fish. In 1774, for example, 1 181 kg of grayling were harvested from the fishing grounds (Haidvogl and Waidbacher 1997). Heckel and Kner (1858) reported specimens of more than 45 cm in length in the Middle Traun near Bad Ischl. The records of Sir Humphry Davy confirm the excellent grayling stock at the beginning of the 19th century, at least in certain places (Wohlschlager, 2002). In the late 19th century, the species was still common and frequent in River Traun (Kukula, 1874). After World War II, no more graylings were delivered to the Linz fish market, possibly the first sign of dwindling T. thymallus stocks in Alpine rivers caused by untreated wastewater discharge from paper mills (Kerschner, 1956). The distribution and dominance conditions of *T. thymallus* in River Traun in the 1950s are stated by Bruschek (1959) as follows: the ratio between grayling and chub was approximately the same as nase and barbel downstream of the weir Wels (~ river-km 28), while upstream grayling, chub, and trout predominated, however, it is not explicitly mentioned whether it is *S. trutta* or *O. mykiss*. Upstream of TF, grayling was one of the dominant species, including trout (mainly rainbow trout) and chub.

According to Kainz (1992), *T. thymallus* formed ~ 36 % of the total fish stock near Bad Ischl in the 1980s, including large adult specimens, but the stock decreased heavily in the following years because of water quality problems, especially downstream of the Ager estuary. In the polluted impoundment section next to Steyrermühl, dead graylings were observed once in a while (Kainz, 1992). In summary, the grayling stock in the River Traun was excellent in former centuries, also benefiting the local fishery. However, the various impacts described in chapter 5.1 have decimated the *T. thymallus* stock significantly over time. Nowadays, the species is protected and listed in annex V of the Austrian "Flora-Fauna-Habitat Guideline" (Umweltbundesamt, 2019).

The analysis of previous fish stock data shows that the *T. thymallus* biomass in the 1980s and 1990s was still relatively high but decreasing ever since as the historical level is no longer reached in the last 40 years (Figure 28). In total, 46 sampling efforts are merged in Figure 28. In the 1980s, the biomass varied between < 1 and 68 kg/ha, averaging 52 kg/ha downstream and 22 kg/ha upstream of TF. Between 1990 and 1999, one survey was carried out downstream of TF resulting in 1 kg/ha grayling biomass. The average biomass from LT to TF was 28 kg/ha, whereas a survey could prove ~ 95 kg/ha grayling biomass in that period. In the middle reach, the grayling occurred in relatively high biomasses in the 1990s, averaging

31 kg/ha. From 2000 to 2009, the grayling biomass has declined dramatically throughout the entire course of the river. Every assessment evidenced less than 7 kg/ha biomass. Since 2010, the grayling biomass is slightly higher than in the previous period, but 10 kg/ha is exceeded only in exceptional cases in the Lower and Middle Traun. Thus, the status of *T. thymallus* regarding biomass is on a very low level in the last 20 years, considering its former dominance in the hyporhithral.

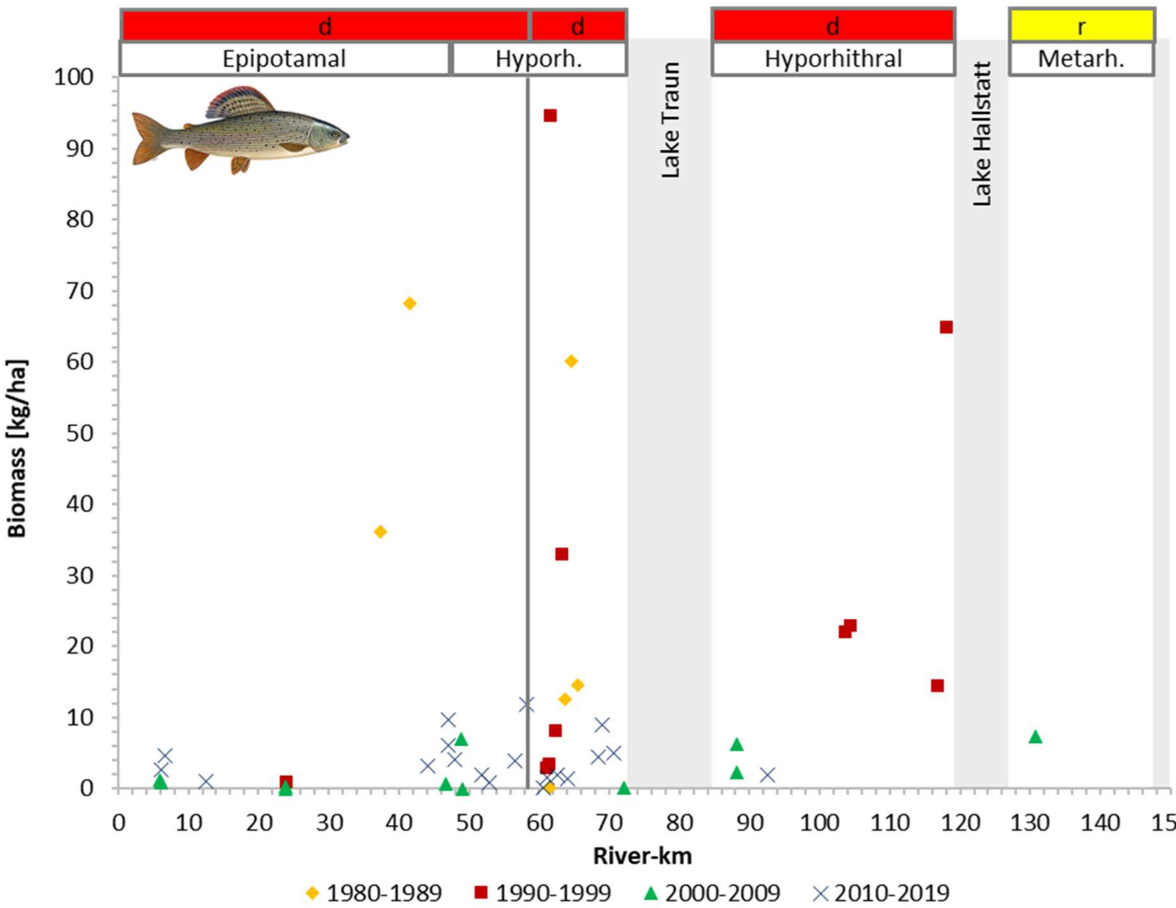


Figure 28: Longitudinal and temporal course of T. thymallus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

The distribution of *T. thymallus* in River Alm is confirmed from the estuary to the higher reaches and Lake Alm. A significant grayling population inhabited the lake, partly migrated upstream into the lake tributaries for spawning, and spawned in shallow places in the lake itself (Einsele, 1962). The species reportedly still occurred in Lake Alm in the last decade (Bacher et al., 2007). *T. thymallus* has been evidenced in six fish stock surveys since 1980 (Figure 29). The biomass was by far the highest in the 1980s, with ~57 kg/ha calculated close to the estuary and 20 kg/ha 2.5 km further upstream. In the 2000s, the stock surpassed

10 kg/ha in one out of three surveys. During the 2019 survey, almost 3 kg/ha biomass was verified (Table 8).

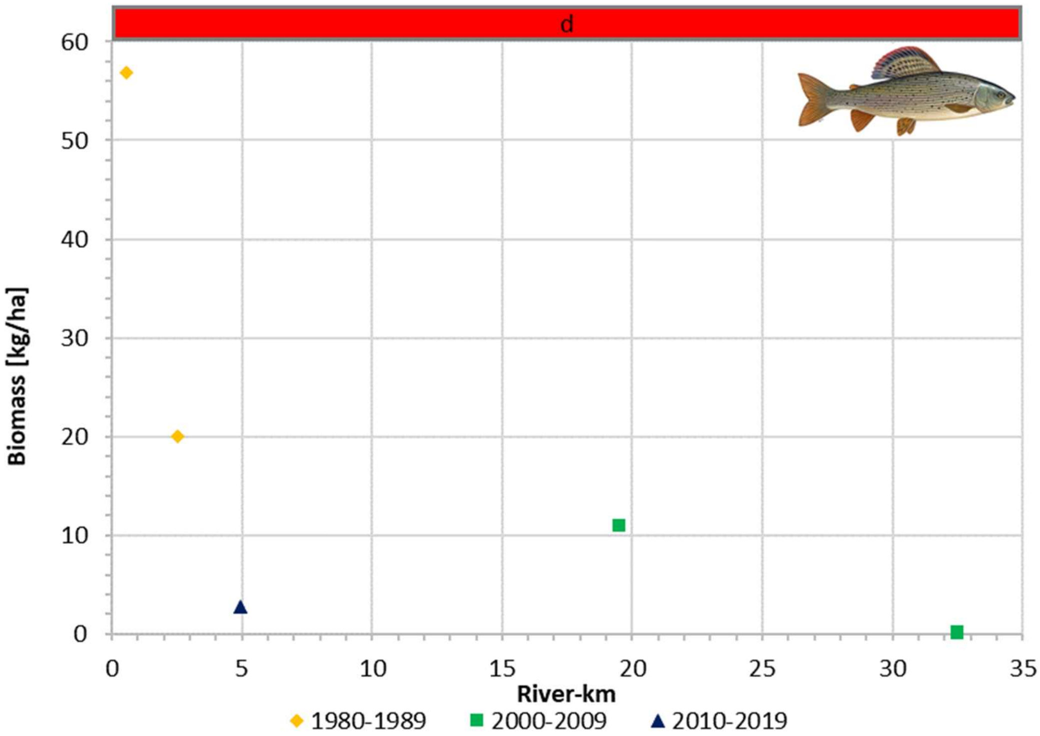


Figure 29: Longitudinal and temporal course of T. thymallus biomass from past fish stock surveys under consideration of the status in the reference list in the River Alm (grouped by decades).

In River Ager, *T. thymallus* was proven in 13 stock surveys in the last 30 years, of which eight have been performed between 1990 and 1999 (Figure 30). In this period, the grayling biomass did not exceed 7 kg/ha, averaging 3 kg/ha. In the following decades´ two assessments, the grayling biomass was extremely low (< 1 kg/ha). From 2010 to 2019, the stock recovered in the lower part as the biomass reached > 15 kg/ha in all surveys. In 2019, the highest grayling biomass ever assessed at the River Ager was proven (20.4 kg/ha) in the fish stock survey.

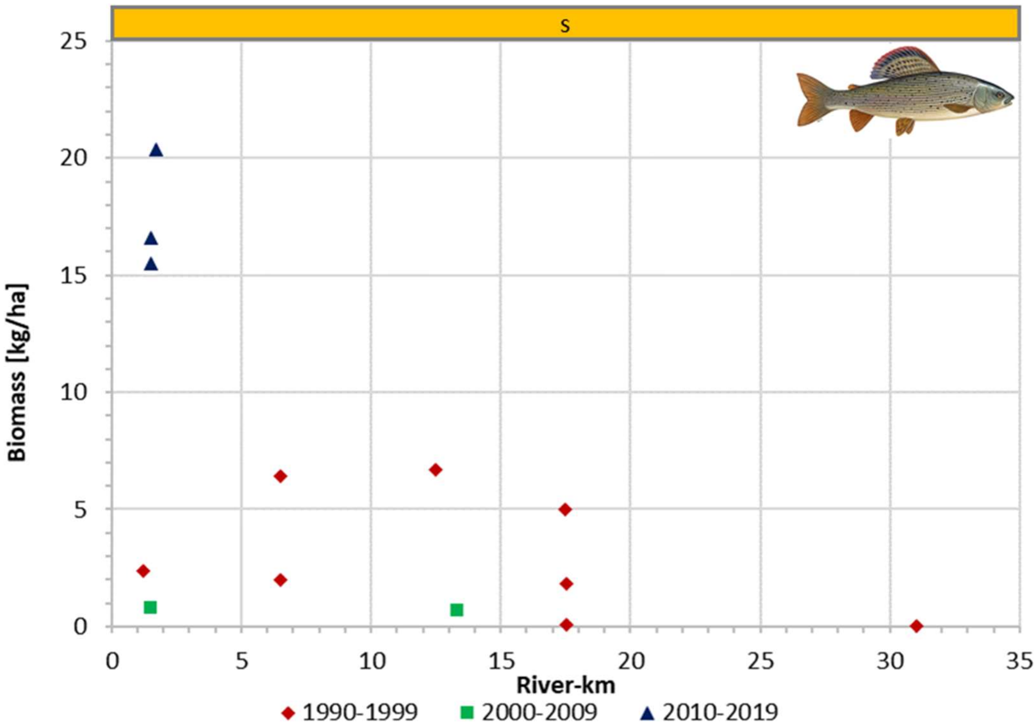


Figure 30: Longitudinal and temporal course of T. thymallus biomass from past fish stock surveys under consideration of the status in the reference list in the River Ager (grouped by decades).

5.2.8.4 *Oncorhynchus mykiss* (Walbaum, 1792)

The rainbow trout was first recorded in the Traun catchment in 1885 when fertilized eggs were sent to Neunkirchen at the River Vöckla, the main tributary of River Ager (Stanković et al., 2015). The economic importance and stocking effort grew in the following decades, especially after World War II, leading to the frequent occurrence of rainbow trout in Austrian rivers (Jungwirth et al., 2003). Evidence of the natural reproduction success of *O. mykiss* in Upper Austria was first given in the 1960s (Stanković et al., 2015). Statistical records from the Linz fish market show that rainbow trout were sold in the early 20th century in relatively small quantities. However, the sales increased from six individuals in 1902 to 120 in 1905 (Kerschner, 1956). In the following years, the stocking measures in the Traun catchment were mainly limited to the rainbow trout because of their presumed broader range of tolerance and their better adaptability to suboptimal habitat conditions compared to other salmonid species (Walder, 2009). Consequently, not the native brown trout but mainly the rainbow trout occurred in the Lower Traun in the late 1950s (Bruschek, 1959).

The biomass of *O. mykiss* in the longitudinal and temporal course at the River Traun is displayed in Figure 31. BOKU's fish stock assessments in 1985 calculated 176 kg/ha biomass at river-km 42 and 84 kg/ha around 4 km further downstream. According to Kainz (1992), the values are related mainly to anthropogenic impacts, with the intensive stocking of rainbow trout in this section of River Traun also contributing to a considerable extent, but nevertheless demonstrate the extraordinary biomass in River Traun in that period, which could not be confirmed to the same extent over the subsequent decades. The biomass exceeds 20 kg/ha sporadically in the following period, e.g., in the metarhithral (1990s/2000s) and downstream of LT in recent years (27 kg/ha in 2016; 28 kg/ha in 2019), but barely exceeded 30 kg/ha in any stock survey in the last four decades.

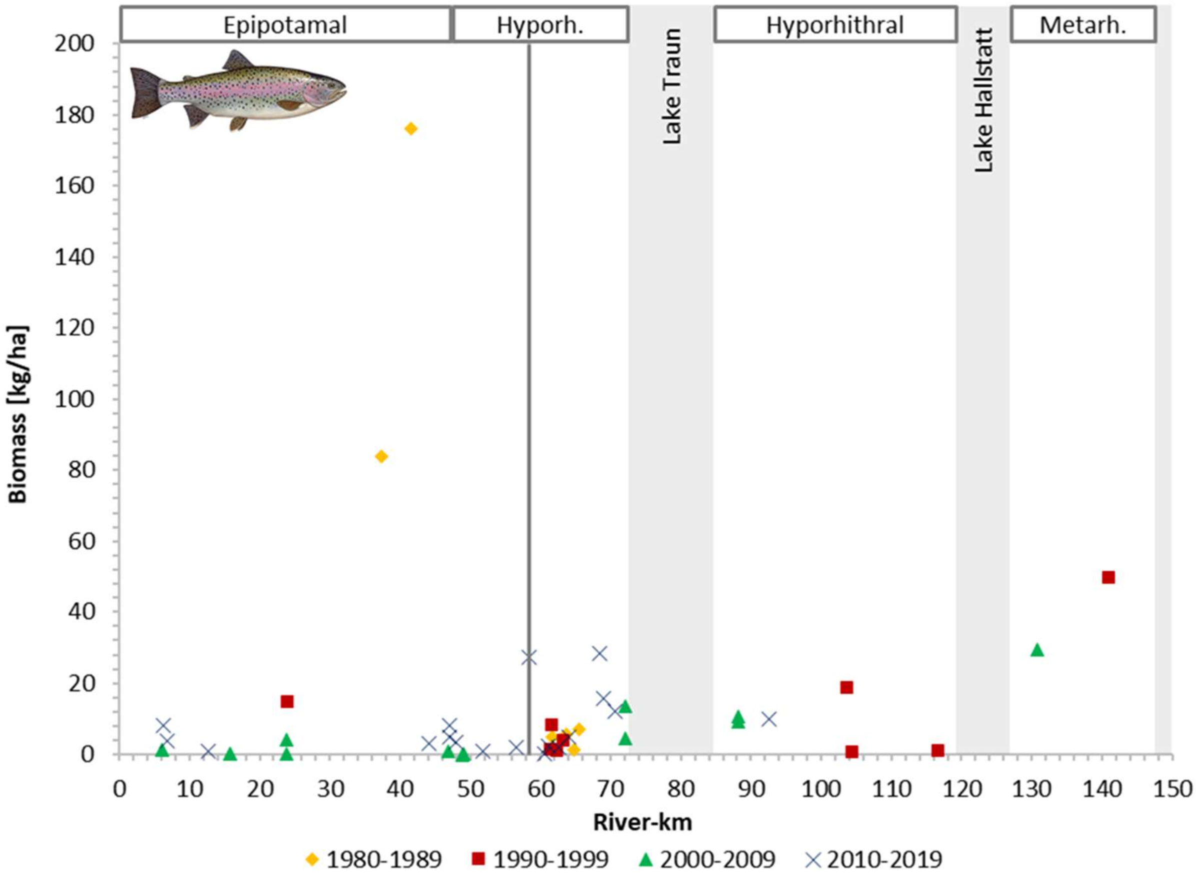


Figure 31: Longitudinal and temporal course of O. mykiss biomass from past fish stock surveys under consideration of the biocenotic region in the River Traun (grouped by decades).

Historical records regarding *O. mykiss* at the River Alm are scarce, but the rainbow trout was reportedly the most abundant fish species in the Alm in the early 1990s (Hofbauer, 1993). *O. mykiss* was proven in eight stock surveys in the past. The highest biomass was recorded in the 1980s with 24.9 kg/ha (Figure 32). In the 2000s, the rainbow trout stock declined sharply, averaging 1.5 kg/ha. In the 2019 campaign, the species biomass of 15 kg/ha was proven.

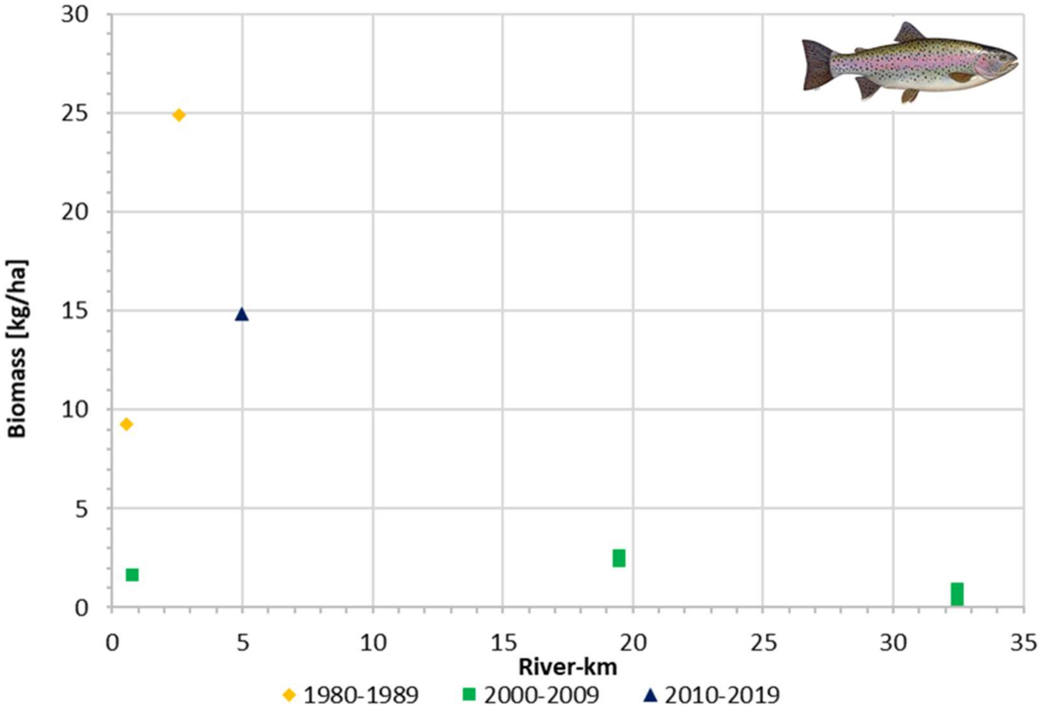


Figure 32: Longitudinal and temporal course of O. mykiss biomass from past fish stock surveys in the River Alm (grouped by decades).

O. mykiss was identified in twelve fish stock surveys at River Ager in the last 30 years, but no evidence of the species was found upstream of river-km 18 (Figure 33). Seven surveys took place in the 1990s, where the highest maximal (28 kg/ha) and average (11.5 kg/ha) biomass were recorded compared to the following years. The single assessment in the 2000s proved 7.6 kg/ha rainbow trout biomass. From 2010 to 2019, the average biomass is < 5 kg/ha.

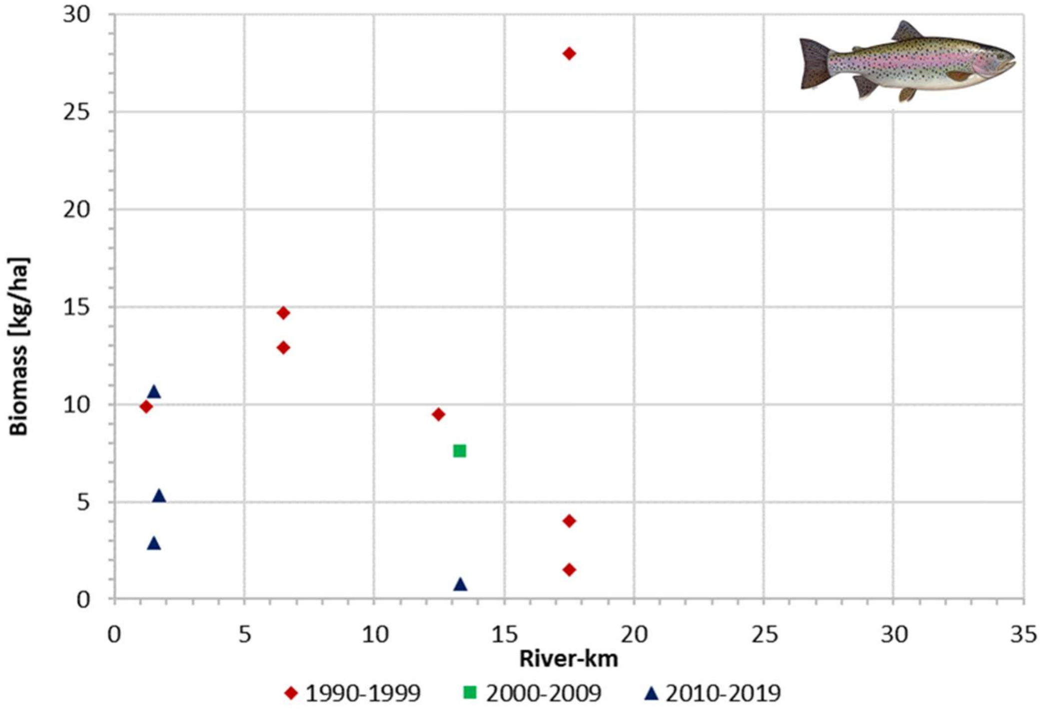


Figure 33: Longitudinal and temporal course of O. mykiss biomass from past fish stock surveys in the River Ager (grouped by decades).

5.2.8.5 *Alburnoides bipunctatus* (Bloch, 1782)

Historical evidence of spirlin (*A. bipunctatus*) was first given for the Lower Traun in the Marchtrenk/Sinnersdorf area in 1701 when the fishing and market regulation dealt with the unit of measurement and price fixing (Scheiber, 1930). Fitzinger (1879) described the spatial distribution of *A. bipunctatus* to LT, which is also confirmed by Gassner et al. (2003), who has proof of spirlin in LT since 1893. The species was sporadically found up to the Bad Ischl area in the 1980s (Kainz, 1992). Due to the low economic interest and value, the historical references are limited, but it is expected that spirlin was also present downstream of LT.

Over the past two decades, recent fish stock surveys limit the distribution of *A. bipunctatus* to the stretch from the Danube to TF (Figure 34). Surprisingly, *A. bipunctatus* could not be proven in fish stock assessments before 2000, although its occurrence is verified in the 1980s (Kainz, 1992). However, in that period, small fish species were rarely quantified in stock surveys. The maximal biomass of 22 kg/ha (2010 to 2019) is reached at river-km 44, located downstream of HPP Lambach. Three out of 13 assessments showed biomasses of > 10 kg/ha, and the remaining are under 4 kg/ha. An upward biomass trend is evident when comparing the recent decade to the years 2000 to 2009.

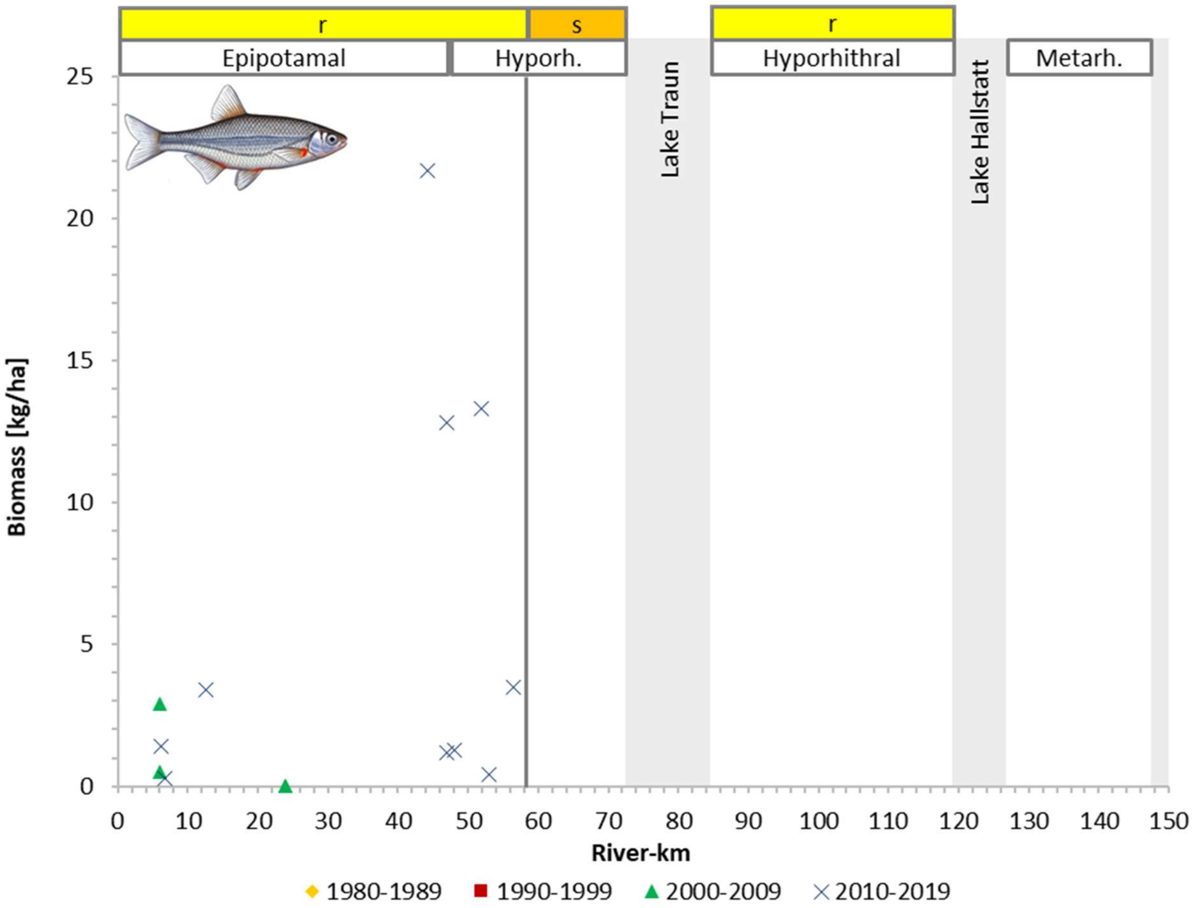


Figure 34: Longitudinal and temporal course of A. bipunctatus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

In fish stock surveys carried out in the 1980s, the spirlin was qualitatively identified in the Ager as a moderately common species in the river mouth (Kainz & Gollmann, 1990). Quantitative assessment results are available from 2000 and show maximal biomass of ~ 11 kg/ha between 2000 and 2010 (Figure 35). In the next decade, three sampling results are available, all located close to the estuary and average ~ 1 kg/ha.

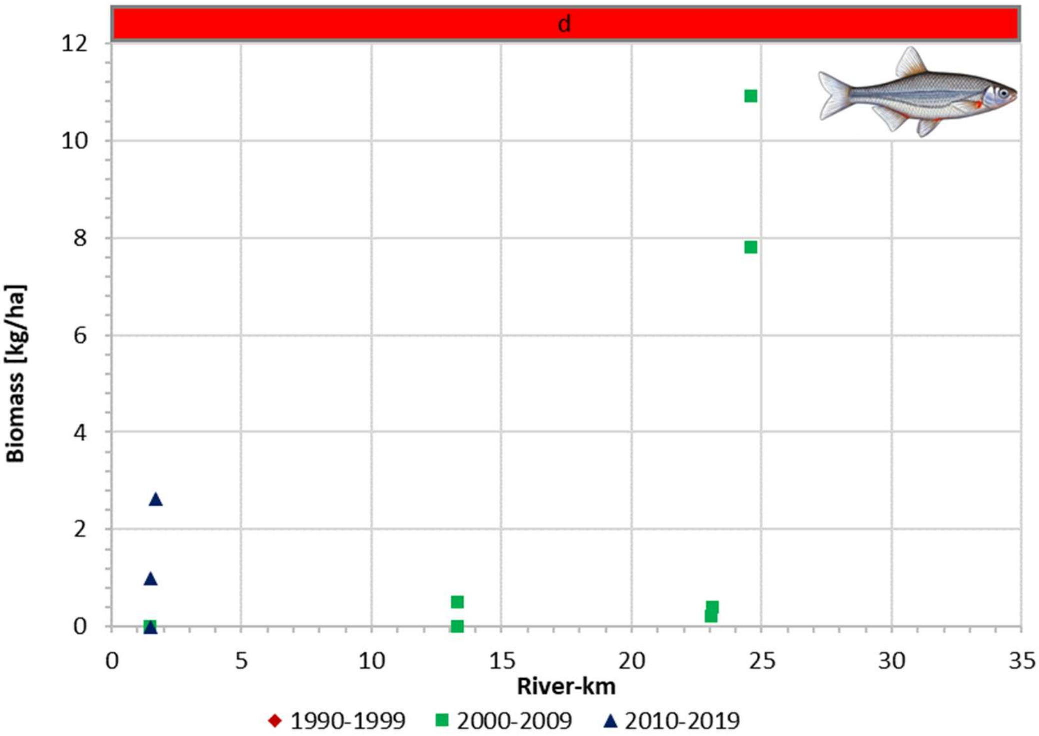


Figure 35: Longitudinal and temporal course of A. bipunctatus biomass from past fish stock surveys under consideration of the status in the reference list in the River Ager (grouped by decades).

5.2.8.6 *Barbus barbus* (Linnaeus, 1758)

The earliest documentation of barbel (*B. barbus*) refers to the first fishing regulations of Upper Austria in 1463 (Brachmann, 1954). The species´ distribution ranges from LT to the Danube. Downstream of TF, the barbel occurred "very frequently" in the late 19th century, which is exemplified by the annual catch of around 1,120 kg, while upstream of TF, the species was found "in profound places" (Borne, 1880; Fitzinger, 1879). Despite the considerable water pollution in the 1950s, *B. barbus* occurred in more significant numbers in the Lower Traun. Some populations occurred permanently, and some migrated upstream from the Danube during the spawning season. The weir at river-km 28 was a difficult barrier to overcome a remnant of the original *B. barbus* population that remained upstream.

Nevertheless, *B. barbus* occurred in relatively high numbers upstream of the Ager estuary, forming a permanent population in River Traun (Bruschek, 1959). In River Ager, historical sources describe the predominance of *B. barbus*, where the species was much more abundant in summer than in winter when the species migrates downstream to their winter habitat (Borne, 1880). In the 1950s, a local fisherman specified the barbel occurrence as follows: “In a diverted channel in the Puchheimer Au south of Attnang-Puchheim, the water stank miserably. By reaching into the water, muddy and slimy depositions accumulated, but the tame barbels occurred in such abundant numbers that they swam staggered on top of each other and made no effort to flee when touched” (Einsele, 1956). The high barbel abundance was also reported in the next decade (Hager, 1965).

B. barbus is proven in 39 sampling efforts at River Traun in the last 40 years (Figure 36). The *B. barbus* stock is higher in the last 20 years than in the former decades. In the fish stock surveys from 1980 to 1989, *B. barbus* shows biomasses of < 10 kg in two of the four assessments. In the following decade, the biomasses decreased to a level below 5 kg/ha, with one exception at ~ 70 kg/ha. Between 2000 and 2009, biomasses of 115 and 133 kg/ha are proven 6 km away from the estuary, while the biomass in the remaining surveys is below 8 kg/ha. In the recent decade, *B. barbus* biomass is higher between TF and LT than in previous periods, averaging 59 kg/ha with a maximum of 214 kg/ha recorded in 2017.

Downstream of TF, the average in the 2010s remains on the level of the previous decade (34 kg/ha). *B. barbus* is detected twice in the Middle Traun in the last 20 years, not belonging to their original distribution. A fish stock survey by the EZB technical office from September 2019, which is not included in the figure below, calculated the *B. barbus* biomass of ~ 88 kg/ha at the site Danzermühl.

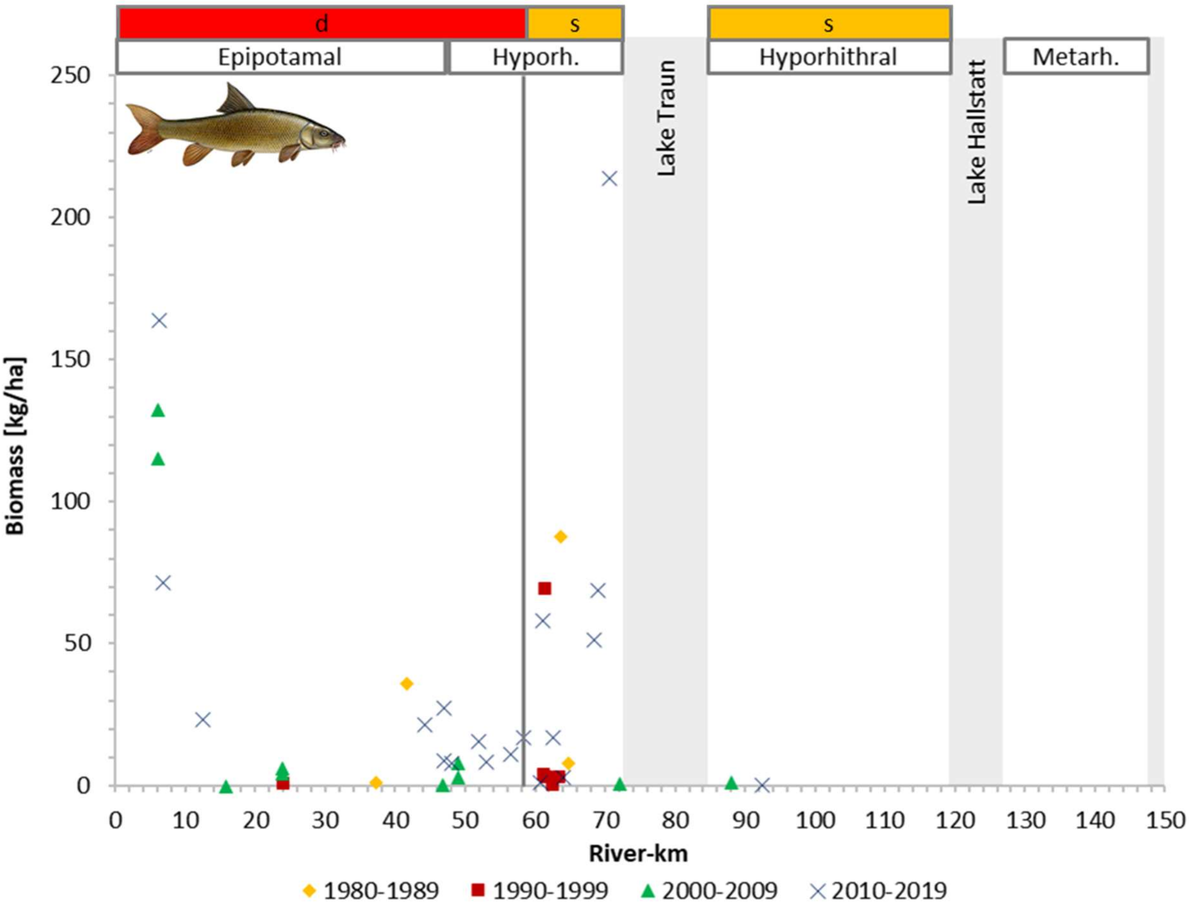


Figure 36: Longitudinal and temporal course of B. barbus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

The occurrence of *B. barbus* is evidenced in 24 fish stock surveys at the River Ager in the last three decades (Figure 37). In the 1990s, the overall maximum biomass of 390 kg/ha was recorded, averaging 46 kg/ha. Between 2000 and 2010, the barbel occurred in relatively low biomasses at river-km 13 and high biomasses between river-km 22 and 25. After 2010, the average biomass is 41 kg/ha; two surveys near the estuary show > 75 kg/ha.

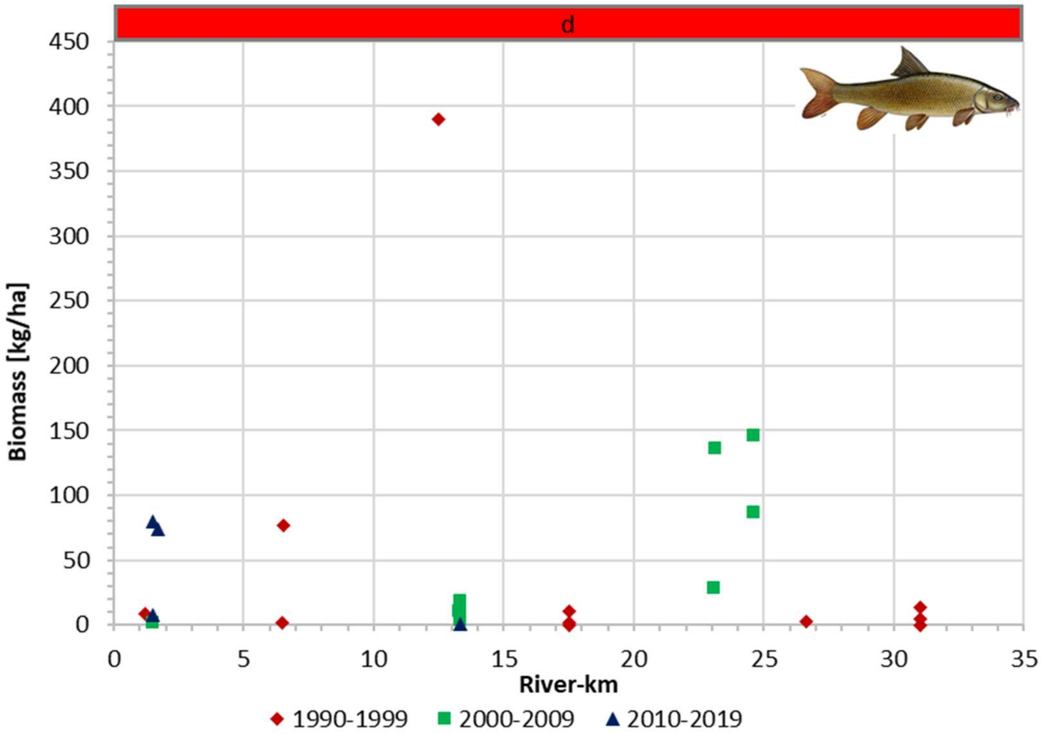


Figure 37: Longitudinal and temporal course of B. barbus biomass from past fish stock surveys under consideration of the status in the reference list in the River Ager (grouped by decades).

5.2.8.7 *Chondrostoma nasus* (Linnaeus, 1758)

From 1537 onwards, the nase (*C. nasus*), called "Näsling" around Linz in the adult stage, was described exclusively for the section between TF and the Danube (Haidvogl & Waidbacher, 1997; Jungwirth et al., 2014; Kerschner, 1956). The fishing regulations of Ferdinand I. stated a minimum harvesting size of ~ 21 cm, but the species was regularly caught below this length. The nase was considered a "common fish," occurring "very frequently" in River Traun (Borne, 1880; Scheiber, 1930). In 1775, almost 2,400 kg were harvested in the fishing districts of Lambach Abbey in the rivers Traun and Ager, confirming the extreme richness of the nase in this region (Haidvogl & Waidbacher, 1997). According to Krafft (1874), 1,680 kg of *C. nasus* were still captured annually in the same fishing district in the second half of the 19th century. Despite the low price and its many bones, the "Näsling" was considered a particularly popular fish on a stick (“Steckerlfisch”). The following statistics underline the economic importance of the species: While in 1905, the overall share of *C. nasus* (all places of origin) at the Linz fish market was around 20 %, the value increased to 33 % in 1951 and 50 % in 1954 (Kerschner, 1956). Despite the considerable water contamination in the 1950s, large *C. nasus* populations were observed in the Lower Traun (Bruschek, 1959). Some individuals inhabited the river stretch permanently, but the majority migrated from the Danube into the rivers Traun and Ager during the spawning season. Close to the Ager confluence near Fischerau, a valuable spawning ground for the species´ reproduction existed (Walder, 2009; Wohlschlager, 2002). The riverbed threshold near Wels (river-km 28) was a migration barrier for the species and is the main reason why only fractions of the original population were found upstream to the mouth of River Ager after its construction (Bruschek, 1959). The species underwent a rapid decline in the second half of the 20th century before disappearing almost entirely in the Lower Traun due to water quality issues and hydropower plant construction (Kainz & Gollmann, 1999). For the reintroduction of *C. nasus* in the Lower Traun, 340,000 individuals were stocked from 2006 to 2009. Except for two confirmed individuals documented in River Traun tributaries, the introduced specimens vanished in the following years since none were proven in subsequent fish stock assessments (Walder, 2009; Zauner et al., 2015). With the stocking of 1,050 specimens in rivers Traun and Ager in spring 2020, fishery managers took another attempt to reintroduce the species in its former range, the prospects of success remain to be verified in the future.

C. nasus was proven in four stock surveys from 2008 to 2014 in River Traun, exclusively situated closer than 7 km from the estuary and below the first weir at Kleinmünchen/ Traunwehr (Figure 38; Table 2). The biomass is 11 kg/ha in 2008 and 27 kg/ha in the following year. In the recent decade, 18 kg/ha (2012) and 13 kg/ha (2014) biomass are reached. The occurrence of the nase could not be detected in River Ager in the last 30 years except for one individual in the 2019 stock assessment.

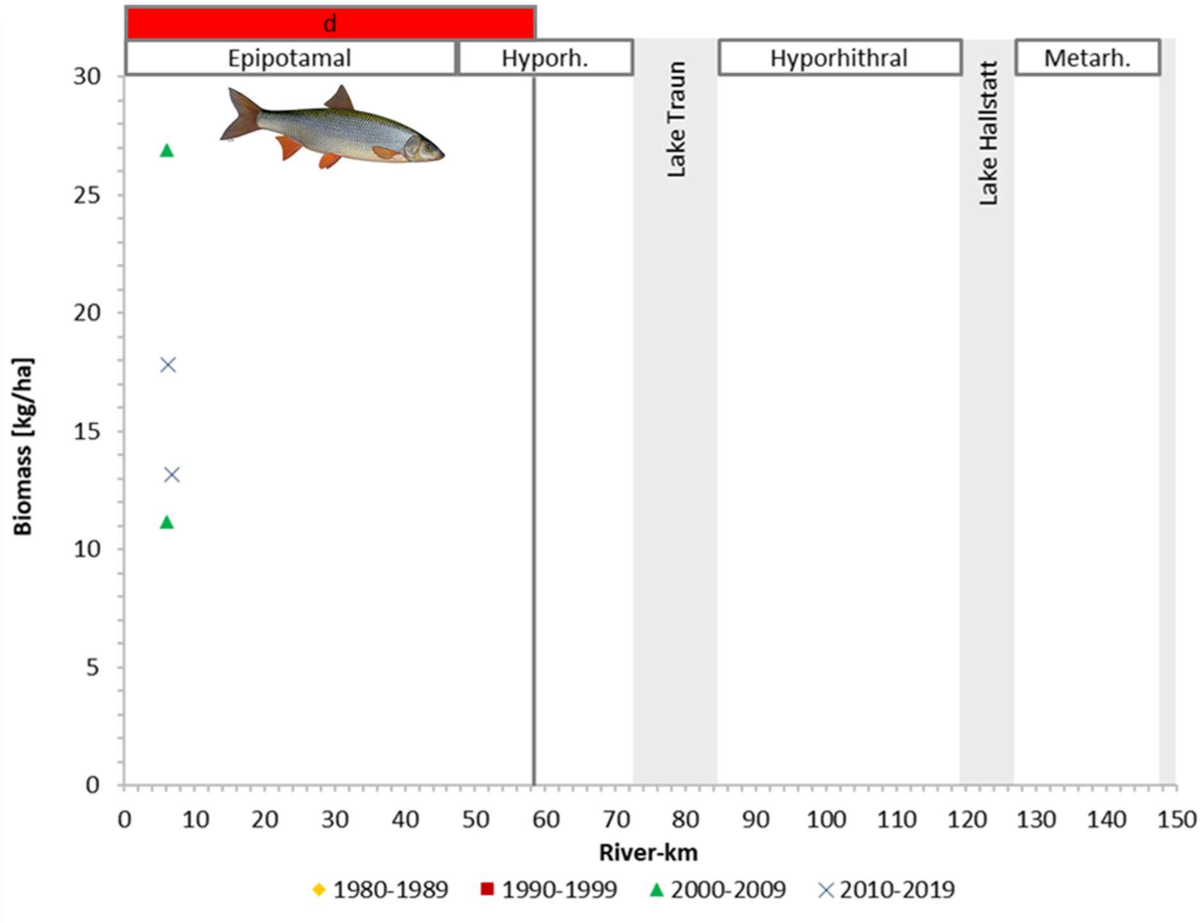


Figure 38: Longitudinal and temporal course of C. nasus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

5.2.8.8 *Phoxinus phoxinus* (Linnaeus, 1758)

The fishery regulation first mentioned the minnow (*Phoxinus phoxinus*) as "Pfrille" in River Traun in the stretch between TF and Danube in 1499, but the species also occurred in LT itself (Gassner et al., 2013; Scheiber, 1930). In the late 19th century, *P. phoxinus* is proven for River Vöckla, where the species occurred numerously and assumed in the River Ager (Borne, 1880). Although the species was sold as a delicacy at the fish market in Linz in the units "Maß or Kandl," the economic value was relatively low (Kerschner 1956). Fishery managers documented the occurrence of *P. phoxinus* until the 1970s upstream of TF. The occasional occurrence of the species in the polluted Lower Ager is confirmed in stock surveys from 1980 in which the species is primarily composed of the 0+ and 1+ generations (Kainz & Gollmann, 1990). Despite considerable investigation efforts and sampling methods during the WFD fish stock assessments of LT in 2012, no evidence of the *P. phoxinus* presence was proven and is considered lost (BAW, 2017). Since 2015, a reintroduction program is launched in several alpine lakes, including LT, where brood fish was taken from LH (BAW, 2017). The success of these measures will be monitored during the following years.

P. phoxinus is quantitatively proven in stock assessments from the metarhithral to the epipotamal of River Traun in the last 30 years (Figure 39) and qualitatively also in the 1980s downstream of TF (Kainz, 1992). The minnow biomasses are low between 1990 and 2019, with some exceptions in the epipotamal, where the species reaches biomasses of 8 to 13 kg/ha in the last decade. In River Ager, the *P. phoxinus* biomass is < 4.5 kg/ha in every case in the last 30 years (data not shown).

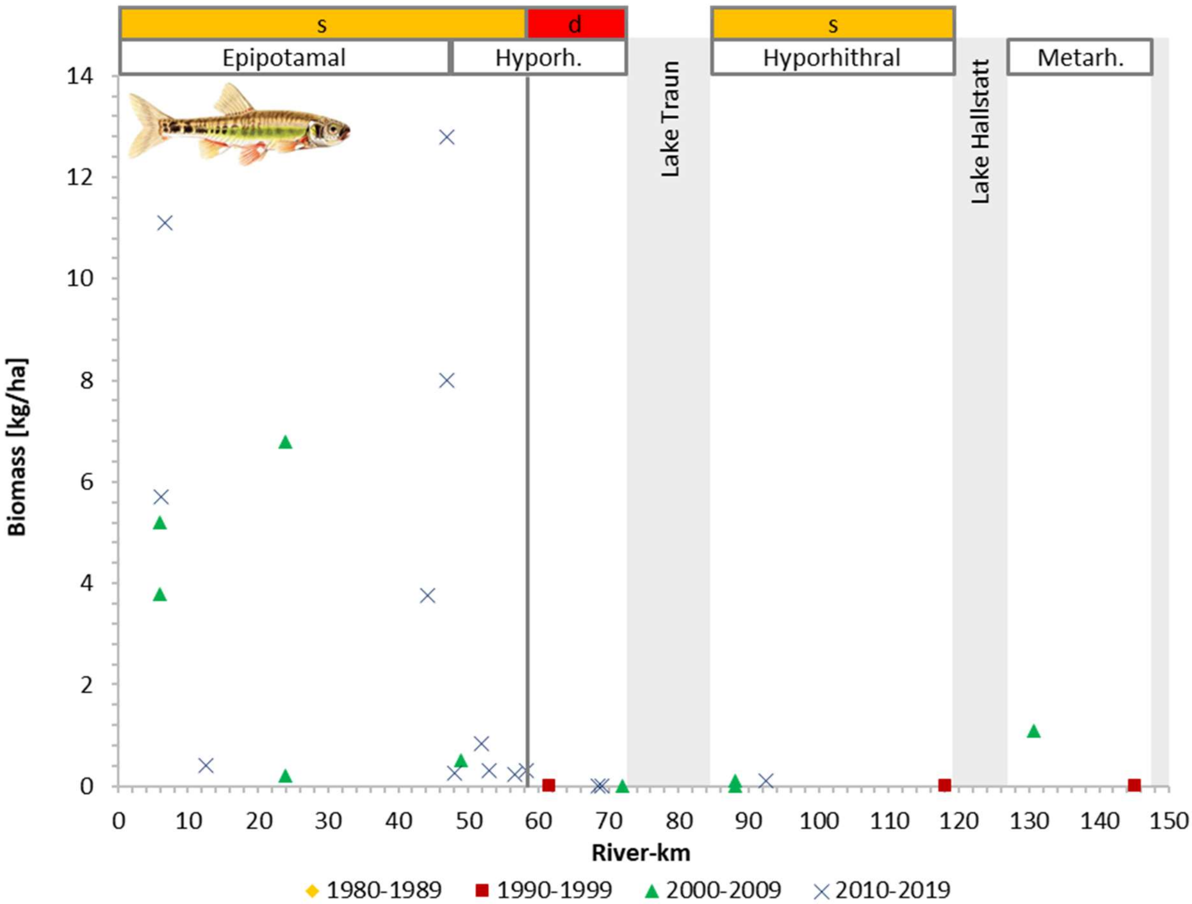


Figure 39: Longitudinal and temporal course of P. phoxinus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

In the catchment of River Alm, *P. phoxinus* is first evidenced in Lake Alm, where the species occurred in large swarms, which were harvested in quantities between 7 and 14 liters per year (Zeitlinger, 1928). During the 2019 assessment, 43 individuals were documented. The biomass was negligible, and the abundance was 189 Ind/ha. Fry and individuals with a TL of 60 to 69 mm mainly dominate the population.

5.2.8.9 *Squalius cephalus* (Linnaeus, 1758)

S. cephalus is first mentioned in the fishing regulations from 1499 (Scheiber, 1930). Local fishers delivered the species to the Lambach Abbey as a substitute levy if they could not catch grayling (Scheiber, 1930). The species is regarded as a "common fish" and frequently occurring downstream of TF, while upstream of TF, it is found "in profound places" (Anonymous, 1895; Scheiber, 1930). *S. cephalus* had moderate economic importance in the early 20th century: The annual sales figures at the fish market of Linz ranged between 3,200 and 4,200 individuals from 1902 to 1905 before decreasing to 400 to 500 individuals in the early 1950s (Kerschner, 1956). In the late 1950s, *S. cephalus* is described as one of the most abundant species besides *C. nasus* and *B. barbus* downstream of the weir Wels at river-km 28, while upstream of the weir, chub and grayling were the dominant species (Bruschek, 1959). Upstream of TF, chub, grayling, and trout predominated the fish fauna (Bruschek, 1959). The original distribution of *S. cephalus* is recorded in the rivers Vöckla and Ager in the late 19th century. Especially downstream of the Vöckla estuary, chub was one of the predominant species (Borne, 1880). *S. cephalus* still occurred in large numbers in the 1960s, which was the main reason why fishery managers attempted to remove as many individuals as possible in order to promote salmonid species (Hager, 1965). After the chlorine accident, chub was the only fish species that survived the incident and recolonized the habitat shortly afterward (chapter 5.1.4; Hauer, 1997).

S. cephalus was documented in 29 fish stock surveys during the last 40 years (Figure 40). The biomass is higher in the last 20 years than in the previous periods. From 1980 to 1999, the *S. cephalus* biomass was low, averaging 4 - 6 kg/ha in the hyporhithral between LT and TF. In the 2000s, the two surveys near the estuary exceeded 100 kg/ha, while the sampling efforts further upstream averaged 18 kg/ha biomass. From 2010 to 2019, an overall increase in chub biomass in the epipotamal/hyporhithral transition area is apparent, as biomasses of > 100 kg/ha occur more frequently, contributing to an increase in average biomass to 54 kg/ha downstream of TF. The average biomass upstream of TF is 16 kg/ha in the recent decade. *S. cephalus* was identified outside its distribution range in the Middle Traun once in the last ten years.

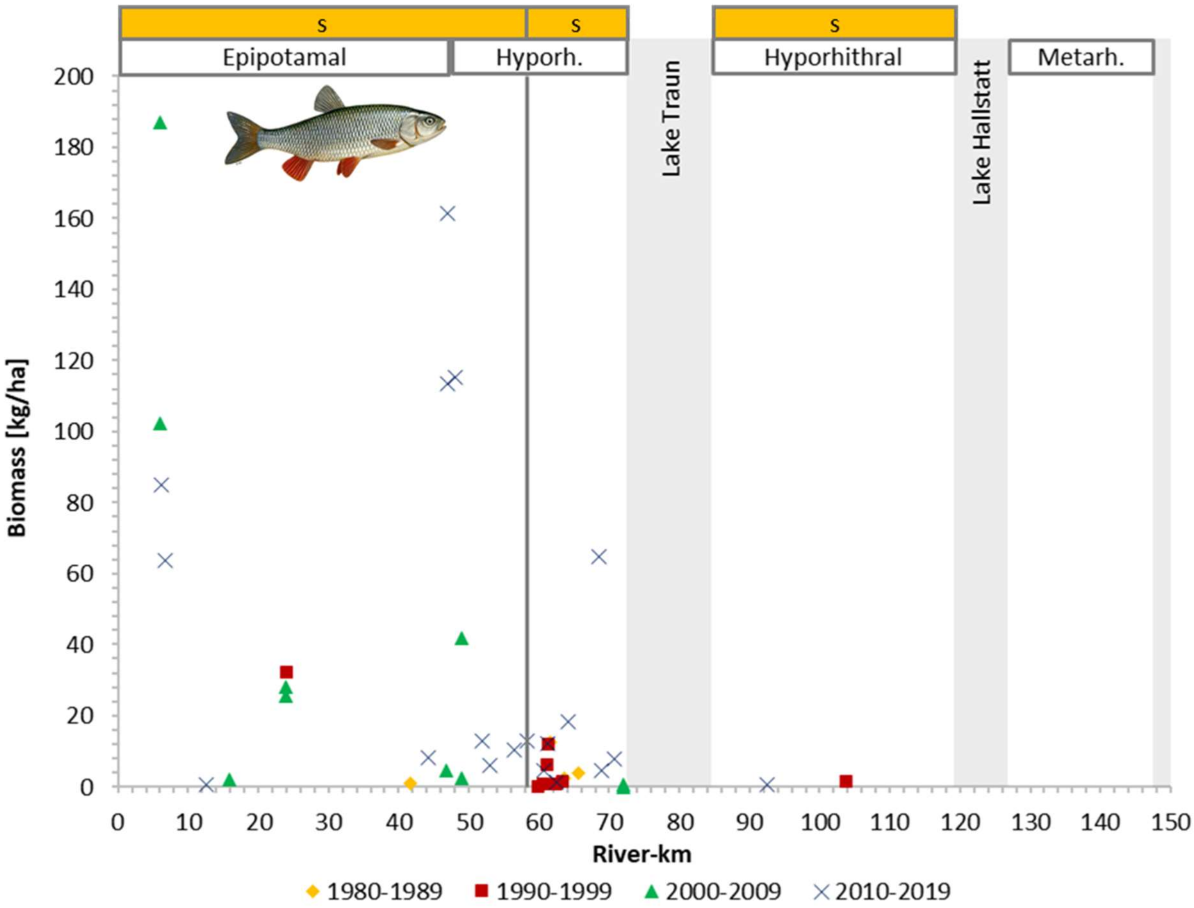


Figure 40: Longitudinal and temporal course of S. cephalus biomass from past fish stock surveys under consideration of the biocenotic region and the status in the reference list in the River Traun (grouped by decades).

S. cephalus was proven in 25 stock surveys in the last three decades in River Ager, partly occurring in very high biomasses above 100 kg/ha (Figure 41). In the 1990s, the maximal biomass was 121 kg/ha, while the average biomass is calculated with 35 kg/ha. In the following decade, the average biomass increased considerably to 173 kg/ha before decreasing to 40 kg/ha in the 2010s.

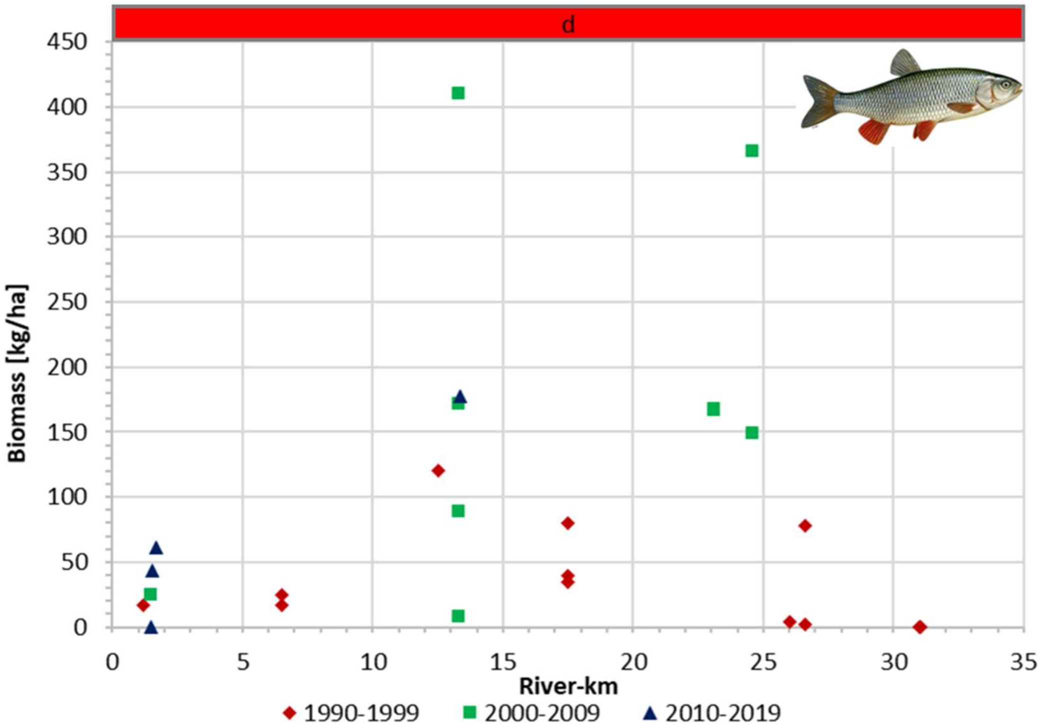


Figure 41: Longitudinal and temporal course of S. cephalus biomass from past fish stock surveys under consideration of the status in the reference list in the River Ager (grouped by decades).

5.2.8.10 Other key species

B. barbatula (Linnaeus, 1758) initially occurred in LT but was not documented during the last fish stock survey (Gassner et al., 2013). During the 2019 stock survey, the species is found in low biomasses downstream of TF. The abundance is highest at the sites Kemating and Lambach with 67 Ind/ha each and does not exceed 5 Ind/ha in the other sites. The sample consists of 31 individuals. All age classes show disturbed distribution, and the 0+ class is entirely missing. *B. barbatula* occurrence is described up to Lake Alm, where a lake population is evidenced in the 1920s (Kukula, 1874; Zeitlinger, 1928). The stone loach has been sampled three times since 2000. The biomass was always below 0.3 kg/ha. The abundance in the 2019 survey was calculated with 70 Ind/ha. The majority had a TL between 80 and 120 mm. *B. barbatula* occurrence is proven for the Vöckla, but not for the Ager itself in the late 19th century (Borne, 1880). The species can be found in almost all waters, even organically heavily polluted rivers. Alongside chub and gudgeons, the stone loach is often the only fish species found there: In waters of the quality class III - e.g., in some residual water areas of the Ager downstream of Lenzing -, *B. barbatula* was responsible for more than 90 % of the overall, but otherwise deficient population (Kainz & Gollmann, 1989). During the 2019 survey, the species was identified in a 17 Ind/ha density and contributed to a minimal extent to the biomass.

C. gobio (Linnaeus, 1758) was first described in 1557 in the Lower Traun (Scheiber, 1930). The species´ territorial and reproductive behavior in the River Traun was described in detail in the 1850s by Heckel and Kner (1858). However, the species completely disappeared in the 1950s in the polluted part downstream of the Ager estuary due to water quality issues and recolonized the river only after the situation improved. The biomass and abundance in the 2019 fish stock assessment did not exceed 1 kg/ha and 61 Ind/ha, respectively. The lowest abundance is documented at Danzermühl (5 kg/ha) and Steyrermühl (2 kg/ha). In total, 30 individuals were captured upstream and 60 downstream of TF. The species is protected and listed in annex II of the Austrian "Flora-Fauna-Habitat Guideline" (Umweltbundesamt, 2019). *C. gobio* distribution in River Alm is the same as described for *B. barbatula* (Zeitlinger, 1928). During the 2019 survey, 187 individuals, 2.6 kg/ha biomass, and 323 Ind/ha were proven. The population structure is healthy with a dominant 1+ age class. The 0+ class was visually identified as abundant on-site but is underrepresented in the population diagram due to their small body size. *C. gobio* occurred in high densities alongside *S. trutta* as an accompanying species in River Ager tributaries, where its distribution is – amongst others- described for Weyreggerbach, Fischerach, and Weissenbach (Borne, 1880). In the late 1980s, the species distribution excluded the region downstream of Lenzing and the lower Vöckla due to water pollution (Kainz & Gollmann, 1989). During the 2019 stock survey, the abundance of 14 Ind/ha and 0.1 kg/ha biomass were calculated.

E. lucius (Linnaeus, 1758) was originally found in "profound places" from Gmunden to Lambach. However, downstream of Lambach, the river contained more pike, barbel, and chub than trout (Borne, 1880). Nowadays, the species occurs in relatively small numbers in River Traun, but some specimens can reach 1 m in length. Six individuals were caught upstream and 34 downstream of TF. The abundance (10 Ind/ha) and biomass (10 kg/ha) are highest in site TF. The species had a decent economic value in historic fishery records, shown in chapter 5.1.7, but hardly reached biomasses of > 10 kg/ha in the last 40 years´ stock surveys.

L. lota (Linnaeus, 1758) is described from the LT to the estuary, although exact distribution limits and centers of distribution are unknown (Haidvogl & Waidbacher, 1997; Heckel & Kner, 1858). The first l evidence was found in the fishing regulations dating from 1499 (Scheiber, 1930). At the beginning of the 20th century, the species had the reputation of being a "spawn predator" for trout larvae, brood, and up to 2-year-old individuals and was therefore not protected in the fishing regulations (Hager, 1965; Kerschner, 1956; Wittmack, 1875). Borne (1880) gives first information about the preferred habitat in the River Traun, where the species occurred mainly in deep places. *L. lota* was found in high biomass a few decades ago. For instance, 166 kg/ha have been documented at the outflow of LH in the 1990s. The following surveys nowhere reached this value in the remaining sampling efforts. The species appeared in LT during assessments a few years ago, where the stock is reportedly on the rise (Gassner, personal communication; Gassner et al., 2013). The last evidence of *L. lota* in the River Traun is downstream of HPP Gmunden in 2017 and downstream of HPP Stadl-Paura in 2018, whereas in the 2019 assessment, the species was completely absent.

P. fluviatilis (Linnaeus, 1758) occurrence in the river is favored because the Traun is a lake outflow, increasing the water temperature naturally and opening the habitat availability to regions upstream of the epipotamal. In the last 40 years, the maximal biomass was 41 kg/ha in 1998 at river-km 24 but is below 10 kg/ha ever since with one exception. During the 2019 assessment, 78 individuals were caught upstream of TF and 40 downstream. The maximal abundance is 78 Ind/ha, and the biomass is below 2.2 kg/ha in every investigated site.

R. meidingeri (Heckel, 1851) inhabits several lakes in the Salzkammergut, including LT, where the species was proven in the last stock survey in 2012 but was not proven further downstream in the site of Gmunden (Gassner et al., 2013). The species migrates into the rivers to shallow spawning grounds for reproduction purposes, where it was often caught but not much appreciated as food fish (Borne, 1880). As there is no evidence of the occurrence in the other stretches, the four individuals caught in the sites Ager and Stadl-Paura in the stock survey of 2019 probably came downstream from Lake Atter. Twenty-two specimens were documented during a fish stock survey upstream of LT near Ebensee in autumn 2017. The species is nationally protected and listed in annexes II and V of the Austrian “Flora-Fauna-Habitat Guideline” (Umweltbundesamt, 2019).

5.3 Fish stock survey 2019

In rivers Traun, Alm, and Ager, fish sampling was conducted between October 21st and October 30th, 2019. The number of strips and their summed length are displayed in Table 6. During five electrofishing days at River Traun, 124 strips with a length of 23 km and a surface of 11 ha were sampled, subdivided into 28 midstream, 24 inner banks, and 16 outer banks, as well as nine inner and outer banks mesohabitats each. Thirty-eight sites are special bank or branch habitats.

The fieldwork at River Alm took three days. In total, 38 strips with a length of 6 km and a surface of 2.5 ha were covered. The most frequently sampled habitat types were outer banks (15), midstream sections (13), and inner banks (9). No shifted inner bank was sampled because the river characteristics do not allow a clear distinction between shifted banks and midstream sections.

Electrofishing at the River Ager was performed on one day. The total 17 strips consisted of six midstream sections, four inner banks, three (shifted) outer banks each, and one shifted inner bank. These habitats sum up to almost 4 km in length and 1.6 ha in surface.

Table 6: Fishing effort in Rivers Traun, Alm and Ager; Rivers Alm and Ager are differentiated in residual water and full water.

Habitat type		Inner bank		Inner bank shifted		Midstream		Outer bank shifted		Outer bank		Bank		Bank/branch		Total	
Count [n]	Length [m]	[n]	[m]	[n]	[m]	[n]	[m]	[n]	[m]	[n]	[m]	[n]	[m]	[n]	[m]	[n]	[m]
1 Gmunden		6	621	3	649	4	1,206	2	540	3	557	6	473	-	-	24	4,046
2 Danzermühl		3	333	1	120	1	188	1	247	1	748	2	135	-	-	9	1,771
3 Steyrermühl		-	-	-	-	5	982	-	-	1	183	4	494	-	-	10	1,659
4 Traunfall		8	658	1	281	4	2,599	1	335	5	507	8	746	1	126	28	5,252
5 Kemating		3	196	1	310	5	2,425	2	513	3	296	3	310	-	-	17	4,050
6 Stadl-Paura		-	-	-	-	5	1,167	1	240	1	301	8	1,036	2	183	17	2,927
7 Lambach		4	434	3	571	4	897	2	467	2	478	4	551	-	-	19	3,398
Traun Total		24	2,242	9	1,931	28	9,464	9	2,342	16	3,070	35	3,745	3	309	124	23,103
Alm 1		2	260	-	-	2	336	-	-	3	443	-	-	-	-	7	1,039
Alm 2		1	178	-	-	2	533	-	-	3	642	-	-	-	-	6	1,353
Alm 3		1	97	-	-	2	475	-	-	2	369	-	-	-	-	5	941
Alm 4		1	115	-	-	2	278	1	81	2	419	-	-	-	-	6	893
Alm 5 - Residual water		1	95	-	-	1	207	-	-	1	194	-	-	-	-	3	496
Alm 6 - Residual water		1	188	-	-	1	120	-	-	1	148	-	-	-	-	3	456
Alm 7 - Residual water		1	105	-	-	1	144	-	-	1	110	-	-	-	-	3	359
Alm 8 - Residual water		1	130	-	-	2	287	-	-	2	360	-	-	-	-	5	777
Alm Total		9	1,168	-	-	13	2,380	1	81	15	2,685	-	-	-	-	38	6,314
Ager - Residual water		3	485	-	-	2	529	-	-	-	-	-	-	-	-	5	1,014
Ager		1	114	1	169	4	1,047	3	757	3	507	-	-	-	-	12	2,594
Ager Total		4	599	1	169	6	1,576	3	757	3	507	-	-	-	-	17	3,608

5.3.1 Traun: Catch numbers and fish species distribution

In total, 3,486 individuals out of 21 species were sampled in the five sampling days at River Traun, of which 772 out of 15 species were caught in the upper three sites of Gmunden (14 species), Danzermühl (nine species), and Steyrermühl (11 species). The remaining 2,714 fish out of 19 species were captured downstream of TF in sites 4 to 7 (Table 7). The highest species number was recorded in Lambach (21), the lowest in sites Kemating and Stadl-Paura (both 14). In sites 1 to 3, only a few specimens of the dominant species *C. gobio*, *P. phoxinus*, *S. trutta*, *T. thymallus* were caught. The dominance ratios are shifting in favor of the subdominant species *S. cephalus* and *B. barbus.* Shares of the subdominant *P. fluviatilis*, *A. mento,* and allochthonous *O. mykiss* exceed 10 % in certain sites, whereas the remaining six species remain below 10 %. The indicator species *L. lota* was not documented. The same applies to five subdominant species (*A. bipunctatus*, *B. barbatula*, *G. gobio*, *L. leuciscus*, and *S. trutta lacustris*) and all rare species but *R. rutilus* in the sites upstream TF. Worth mentioning is the proof of three rare and endangered *R. meidingeri* individuals in site 6 (Stadl-Paura) just below the Ager estuary. The upstream succession of the invasive species *P. semilunaris* from site 7 to site 4 but also reaching site 3 upstream of TF is an issue of ecological concern.

Catch numbers and share of small fish species, especially *A. bipunctatus* (> 40 % share in three sites) and *P. phoxinus* (> 10 % in Stadl-Paura/Kemating), which were practically absent upstream TF are more abundant in the sites 4 to 7. The dominant species *B. barbus* shows higher shares than 10 % in site Kemating and 20 % in site Lambach, respectively. The remaining indicator species, *T. thymallus,* does not contribute to more than 6% of the catch in the sites downstream of TF, whereas *C. nasus* is entirely missing. Absent or subdominant species in the sites downstream of TF are *A. brama, A. alburnus, L. idus*, and *L. lota*. Besides *A. bipunctatus* and *A. mento*, 20 rare species from the reference fish assemblage are absent in the sites Traunfall to Lambach.

Table 7: Reference fish assemblage, real catch, and fish species distribution of caught fish at the River Traun; sampling sites upstream (Gmunden to Steyrermühl) and downstream of TF (Traunfall to Lambach) are shown separately and in total.

Species	**Ref.**[1]	**Gmunden**		**Danzermühl**		**Steyrermühl**		**Ref.**[2]	**Traunfall**		**Kemating**		**Stadl-Paura**		**Lambach**		**Total**	
		n	%	n	%	n	%		n	%	n	%	n	%	n	%	n	%
Abramis brama	r	-	-	-	-	-	-	s	-	-	-	-	-	-	-	-	-	-
Acipenser ruthenus		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Alburnoides bipunctatus	s	-	-	-	-	-	-	r	300	56	397	61	99	14	332	40	1,128	32
Alburnus alburnus		2	<1	-	-	2	2	s	-	-	-	-	-	-	-	-	4	<1
Alburnus mento	s	27	5	13	10	14	11	r	3	<1	6	<1	1	<1	-	-	64	2
Barbatula barbatula	s	-	-	-	-	-	-	s	2	<1	18	3	3	<1	8	1	31	<1
Barbus barbus	s	56	11	25	20	48	37	d	38	7	76	12	40	6	191	23	474	14
Carassius carassius		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Chondrostoma nasus		-	-	-	-	-	-	d	-	-	-	-	-	-	-	-	-	-
Cobitis elongatoides		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Coregonus sp.	r	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Cottus gobio	d	25	5	4	3	1	<1	s	34	6	10	2	4	<1	12	1	90	3
Esox lucius	s	1	<1	3	2	2	2	s	16	3	-	-	15	2	3	<1	40	1
Eudontomyzon mariae	r	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Gobio gobio	s	-	-	-	-	-	-	s	-	-	-	-	24	4	13	2	37	1
Gymnocephalus cernua		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Hucho hucho		4	<1	-	-	-	-	s	2	<1	1	<1	1	<1	-	-	8	<1
Leuciscus idus		-	-	-	-	-	-	s	-	-	-	-	-	-	-	-	-	-
Leuciscus leuciscus	s	-	-	-	-	-	-	s	-	-	1	<1	5	<1	-	-	6	<1
Lota lota	d	-	-	-	-	-	-	s	-	-	-	-	-	-	-	-	-	-
Misgurnus fossilis		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Oncorhynchus mykiss		77	15	8	6	1	<1		10	2	4	<1	4	<1	10	1	114	3
Perca fluviatilis	s	50	10	3	2	25	19	s	9	2	2	<1	26	4	4	<1	119	3
Phoxinus phoxinus	d	1	<1	-	-	-	-	s	35	7	40	6	66	10	178	21	320	9
Proterorhinus semilunaris		-	-	-	-	4	3		9	2	7	1	15	2	15	2	50	1
Pseudorasbora parva		-	-	-	-	-	-		-	-	-	-	-	-	1	<1	1	<1
Rhodeus amarus		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Rutilus meidingeri	r	-	-	-	-	-	-	r	-	-	-	-	3	<1	-	-	3	<1
Rutilus pigus		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Rutilus rutilus	r	34	7	-	-	-	-	s	2	<1	-	-	1	<1	-	-	37	1

Species	Ref.[1]	Gmunden		Danzermühl		Steyrermühl		Ref.[2]	Traunfall		Kemating		Stadl-Paura		Lambach		Total	
		n	%	n	%	n	%		n	%	n	%	n	%	n	%	n	%
Salmo trutta	d	29	6	1	<1	1	<1	s	6	1	17	3	1	<1	19	2	74	2
Salmo trutta lacustris	s	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Sander lucioperca		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Scardinius erythrophthalmus		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Silurus glanis		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Squalius cephalus	s	196	38	63	49	29	22	s	52	10	67	10	337	49	33	4	777	22
Squ. cep. x Alb. men.		1	<1	-	-	-	-		-	-	-	-	-	-	-	-	1	<1
Telestes souffia		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Thymallus thymallus	d	11	2	8	6	3	2	d	18	3	7	1	40	6	21	3	108	3
Tinca tinca	r	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Vimba vimba	r	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Zingel streber		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Zingel zingel		-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-
Total	22	514	100	128	100	130	100	39	536	100	653	100	685	100	840	100	3,486	100

[1] (Gassner et al., 2003; Pesendorfer & Schützinger, 1994)

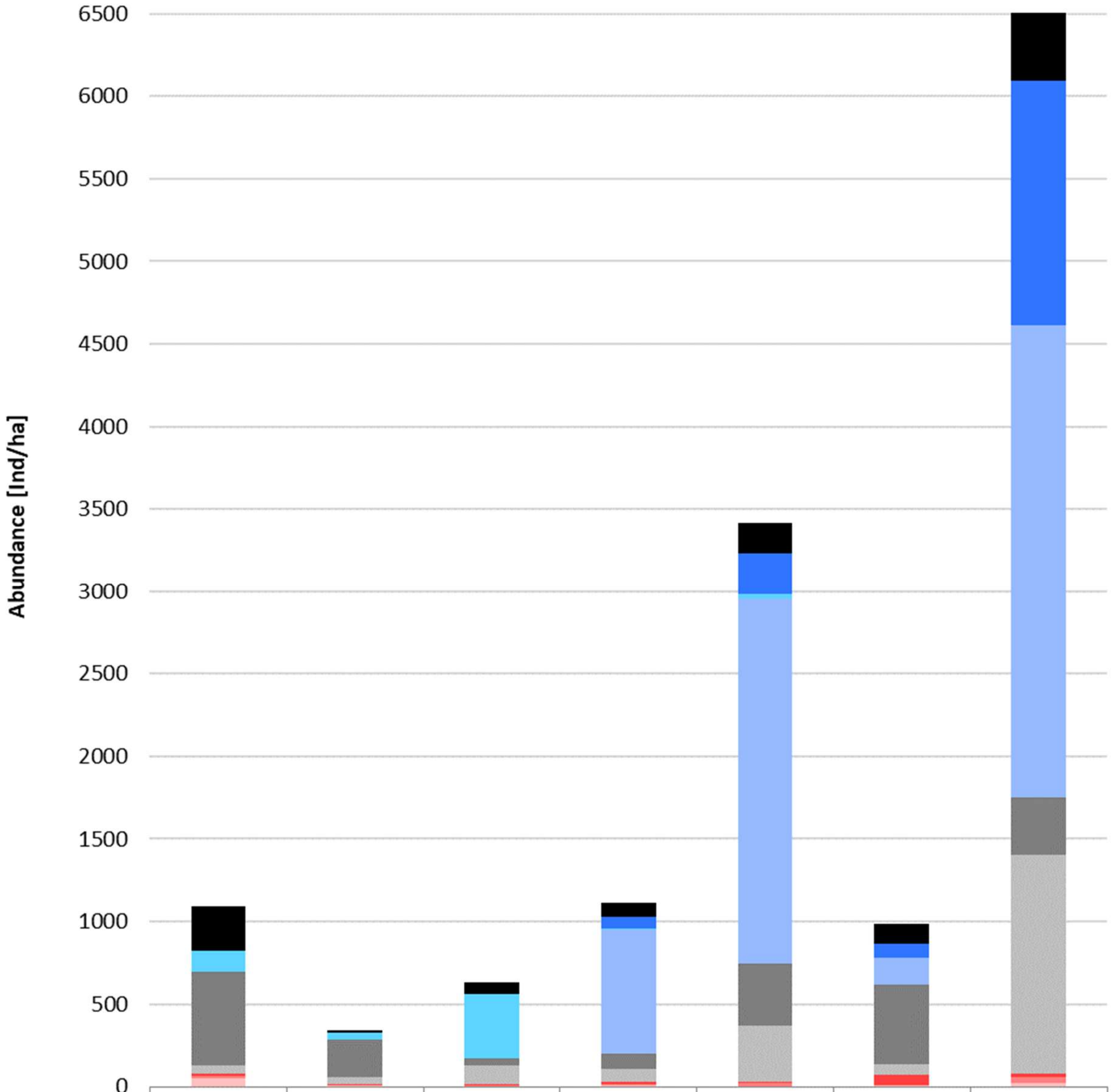
[2] (Kainz, 1992)

In all sites (1 to 7), *A. bipunctatus* dominates the investigated area of River Traun with a 32 % share out of the 21 species, followed by *S. cephalus* (22 %). Besides 14 % of *B. barbus*, the other species, including the dominant species *C. gobio*, *P. phoxinus*, *S. trutta*, and *T. thymallus,* remain below 10 %. Particularly noteworthy is that all salmonid species account for less than 3 % of the total captured individuals in the investigated stretch of River Traun

5.3.2 Traun: Abundance and biomass

The highest abundance is recorded in site Lambach with ~ 6,500 Ind/ha, the second-highest in Kemating with ~ 3,400 Ind/ha (Figure 42). Three sites (Gmunden, TF, Stadl-Paura) show a similar density around 1,000 Ind/ha, while at the sites Steyrermühl and Danzermühl, the abundance is below 1,000 Ind/ha. It is noticeable that in the sites upstream of TF *S. cephalus* and *A. mento* dominate the abundance distribution, whereas in sites 4 to 7 *A. bipunctatus*, *B. barbus*, and *S. cephalus* make up the majority of the species density; *P. phoxinus* represents the second-highest abundance in site 7. Except for site 6 (Stadl-Paura), the endemic salmonid species are in neither site found in higher densities than 33 Ind/ha. Free-flowing stretches exhibit higher abundances compared to impounded sections, which is in detail analyzed in chapter 5.3.4.

In the first and second sampling sections of Gmunden and Danzermühl, the abundance is dominated by 52 % and 66 % of *S. cephalus*, respectively. In the Steyrermühl sampling area, the total abundance from Danzermühl almost doubles (628 Ind/ha), which is 80 % composed of *A. mento* (61 %) and *B. barbus* (19 %). In site Traunfall, 1,112 Ind/ha are recorded. *A. bipunctatus*, which is not found upstream of TF, is the most dominant, with 750 Ind/ha. At Kemating, the total abundance of 3,414 Ind/ha is again dominated by *A. bipunctatus,* with around two-thirds of the total specimens. In the site of Stadl-Paura, *S. cephalus* accounts for roughly half of the total abundance of 985 Ind/ha. *A. bipunctatus* is not documented in the site Stadl-Paura to the same extent as in the adjacent sites (16 %). In the most abundant site of Lambach, in total 6,520 individuals occur per hectare, of which especially small fish species form the more significant part. *A. bipunctatus* (44 %), *P. phoxinus* (23 %), and *B. barbus* (20 %) make up 87 % of the total abundance. Further data on the species abundance are shown in Table 14.



	Gmunden	Danzermühl	Steyrermühl	Traunfall	Kemating	Stadl-Paura	Lambach
Other	271	13	71	87	184	120	423
P.phoxinus	1			68	249	86	1483
A.mento	123	46	385	7	24	1	
A.bipunctatus				750	2210	162	2863
S.cephalus	566	227	42	93	376	482	344
B.barbus	56	40	119	78	343	58	1327
T.thymallus	10	8	7	11	4	66	24
S.trutta	16	1	2	8	23	2	33
O.mykiss	49	6	2	8	2	7	23

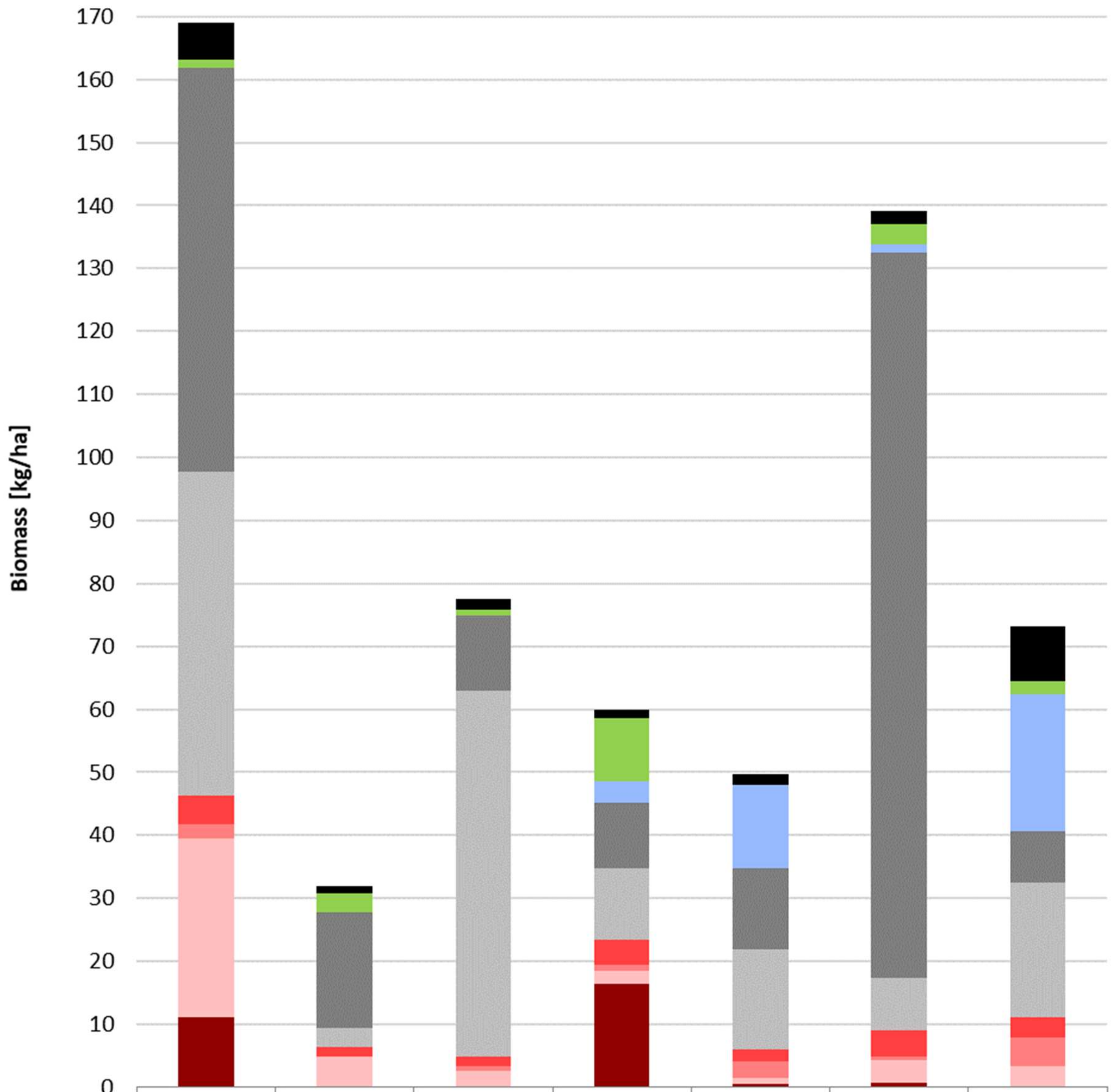
Figure 42: Fish abundance (Ind/ha) in the River Traun. Selected species of high abundance or special relevance in the coenosis are presented. All other species are summarized (appendix Table 14).

The biomass is highest at the site Gmunden (169 kg/ha) and second highest in site Stadl-Paura (139 kg/ha), as shown in Figure 43. Sites 3, 4, and 7 range between 60 and 79 kg/ha in biomass. Biomass below 50 kg/ha was documented in Kemating and Danzermühl (32 kg/ha). It is emphasized that the native salmonid species *H. hucho*, *S. trutta*, and *T. thymallus* occur in small populations of mostly less than 5 kg/ha throughout the investigated sites. Except for site Gmunden, the same applies to the allochthonous *O. mykiss*. The dominant species in terms of biomass are cyprinids *S. cephalus* and *B. barbus*. The two species are mainly stock-forming upstream of TF and are also downstream of TF prominent, together with the emerging *A. bipunctatus*. The biomass in hydrologically impacted river stretches is generally minimal compared to the free-flowing portions, which is in detail presented in chapter 5.3.4.

In the first site downstream of HPP Gmunden, 14 fish species were caught, of which *S. cephalus* (64 kg/ha), *B. barbus* (51 kg/ha), and *O. mykiss* (28 kg/ha) make up 85 % of the total biomass. The catch of four adult *H. hucho* individuals with a TL between 830 and 870 mm in this stretch resulted in 11 kg/ha biomass. However, the species is not mentioned in the reference list in this section of River Traun (Table 7). In site Danzermühl *S. cephalus* accounts for 57 % and *O. mykiss* for 15 % of the biomass of 32 kg/ha. In the Steyrermühl sampling area, the total biomass of 78 kg/ha is detected. 90 % of the calculated biomass comprises *B. barbus* (74 %) and *S. cephalus* (15 %). In site 4, the biomass of ~10 kg/ha to 16 kg/ha is evenly distributed between four species (*B. barbus*, *E. Lucius, H. hucho*, and *S. cephalus*) compared to the other sites. Site Kemating accounts for just under 50 kg/ha biomass, which is 84 % is composed of *B. barbus* (16 kg/ha), *A. bipunctatus,* and *S. cephalus* (13 kg/ha each). In the stretch of Stadl-Paura, *S. cephalus* has a share of 84 % in the total biomass of 139 kg/ha, comprising 18 species. The other species do not exceed 8 kg/ha. In the lowest site of Lambach, *A. bipunctatus* forms the highest biomass with 22 kg/ha. *B. barbus* (21 kg/ha) and *S. cephalus* (8 kg/ha) are noteworthy contributors to the overall biomass of 73 kg/ha in this river stretch.

B. barbus, *T. thymallus,* and *O. mykiss* seem to favor midstream mesohabitats, as a large part of the biomass of these species has been detected in these habitats (Appendix Table 11). In the outer banks, *S. cephalus* and *O. mykiss* occur in higher biomasses than other species. At the same time, the occurrence of *A. bipunctatus* is limited to the immediate vicinity of the banks. In bank habitats within 2 m from the shore, 92 kg/ha are found, preferably occupied by small fish species or juvenile specimens of *A. bipunctatus, B. barbus,* and *S. cephalus*.

Bank/branch habitat is characterized by reduced flow velocity conditions and denser macrophyte vegetation, mainly inhabited by *E. lucius* and *S. cephalus*.



	Gmunden	Danzermühl	Steyrermühl	Traunfall	Kemating	Stadl-Paura	Lambach
Other	6	1	2	1	2	2	9
E.lucius	1	3	1	10		3	2
A.bipunctatus				3	13	1	22
S.cephalus	64	18	12	11	13	115	8
B.barbus	51	3	58	11	16	8	21
T.thymallus	4	1	2	4	2	4	3
S.trutta	2	0	1	1	3	1	5
O.mykiss	28	5	3	2	1	4	3
H.hucho	11			16	1	1	

Figure 43: Fish biomass (kg/ha) in the River Traun. Selected species of high biomass or special relevance in the coenosis are presented. All other species are summarized (appendix Table 14).

5.3.3 Traun: Population structure of selected fish species

Salmonid species

The population structure of the salmonid species *H. hucho*, *O. mykiss*, *S. trutta*, and *T. thymallus* in River Traun are depicted in Figure 44. It is noticeable that each investigated species shows deficits in the population composition, which is particularly apparent in the absence or underrepresentation of the 0+ and 1+ generations. The state of salmonid populations is classified as poor overall with little or no natural reproduction. A high proportion of *O. mykiss* and *S. trutta* were visually identified as hatchery fish by their body shape, short fins, or atypical coloration.

In the case of *H. hucho*, the population's reproduction success is doubtful, as no juveniles and sub-adult individuals were documented in River Traun but only eight adult fish.

In total, 114 individuals of *O. mykiss* were caught, of which the catch upstream of TF is assembled by 86 individuals. The majority had a TL of > 320 mm. Downstream of TF, 25 % of the fish from the total catch is evidenced. The 0+ and 1+ age class is highly underrepresented in both sections, indicating unsuccessful spawning.

Seventy-three *S. trutta* were sampled in River Traun, of which 31 individuals with smaller size assemble the population upstream of TF. In contrast, downstream of TF, more and larger individuals of brown trout were proven. The 0+ and 1+ age class is highly underrepresented in both sections, indicating unsuccessful spawning. The relatively high proportion of adult individuals of > 250 mm downstream of TF might indicate a high reproduction potential but is caused by the stocking of catchable-sized fish in this case.

T. thymallus was identified 108 times during the assessment, of which 22 were caught upstream of TF. All age classes are highly underrepresented, indicating unsuccessful spawning. Downstream TF, more and smaller individuals of the species were sampled; 72 % of the specimens with a length between 100 and 200 mm are found in a 100 m residual water stretch downstream of the weir of HPP Stadl-Paura. Individuals between 200 and 280 mm are mostly missing in the entire investigated area.

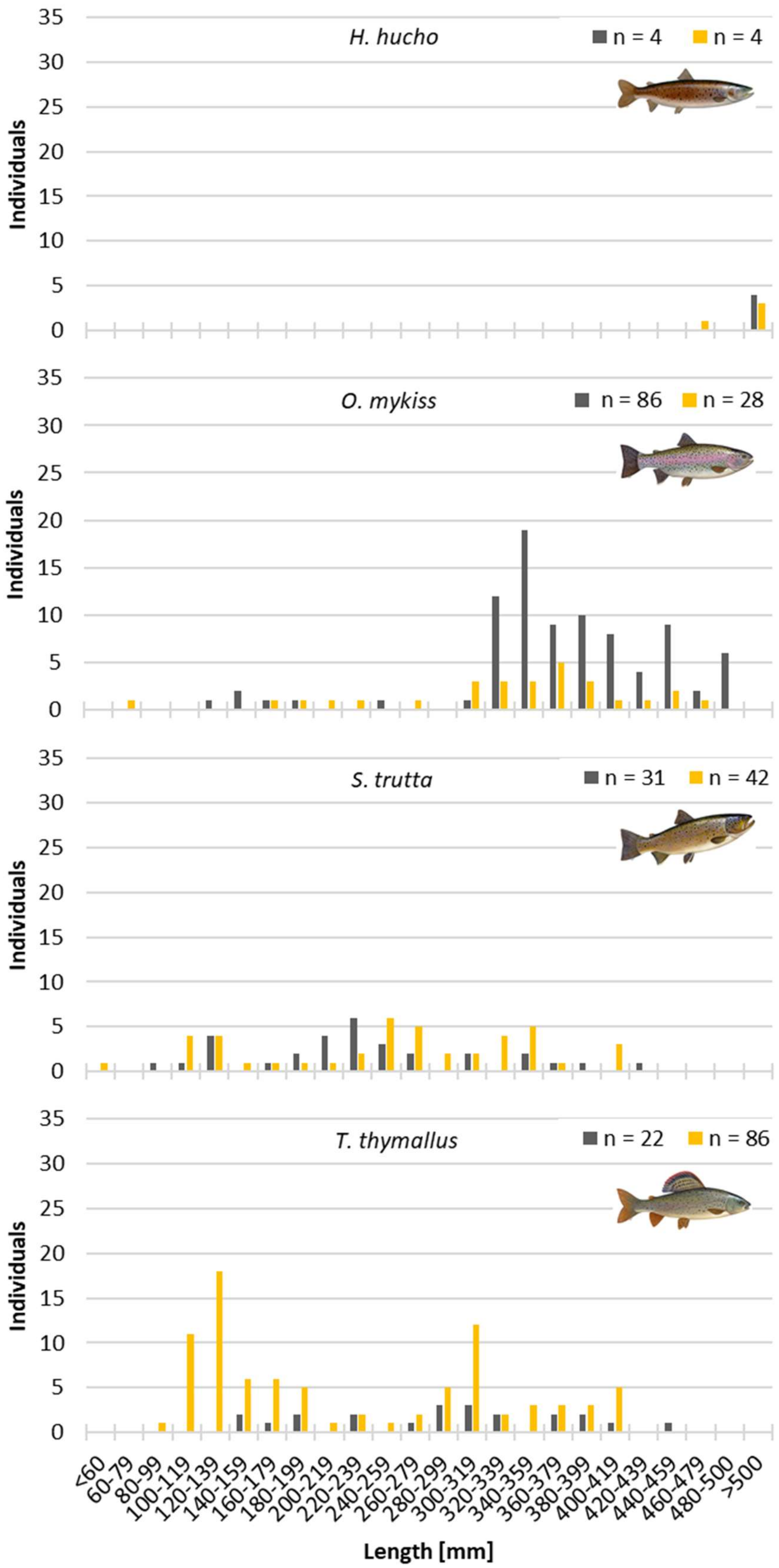


Figure 44: Population structure of H. hucho, O. mykiss, S. trutta, and T. thymallus in River Traun (grey: upstream of TF; gold: downstream of TF).

Cyprinid species

The population structure of *B. barbus* differs depending on the location (Figure 45). Upstream of TF, in total 129 individuals were captured. The 0+, 1+, and older age classes are underrepresented, excluding adults with a TL of > 500 mm. Downstream of TF, the 0+ and 1+ generations are dominant. Specimens with a TL between 160 mm/180 mm and 500 mm are largely missing in River Traun, while individuals with > 500 mm occur disproportionately numerous in the entire study area of the river compared to the other age classes.

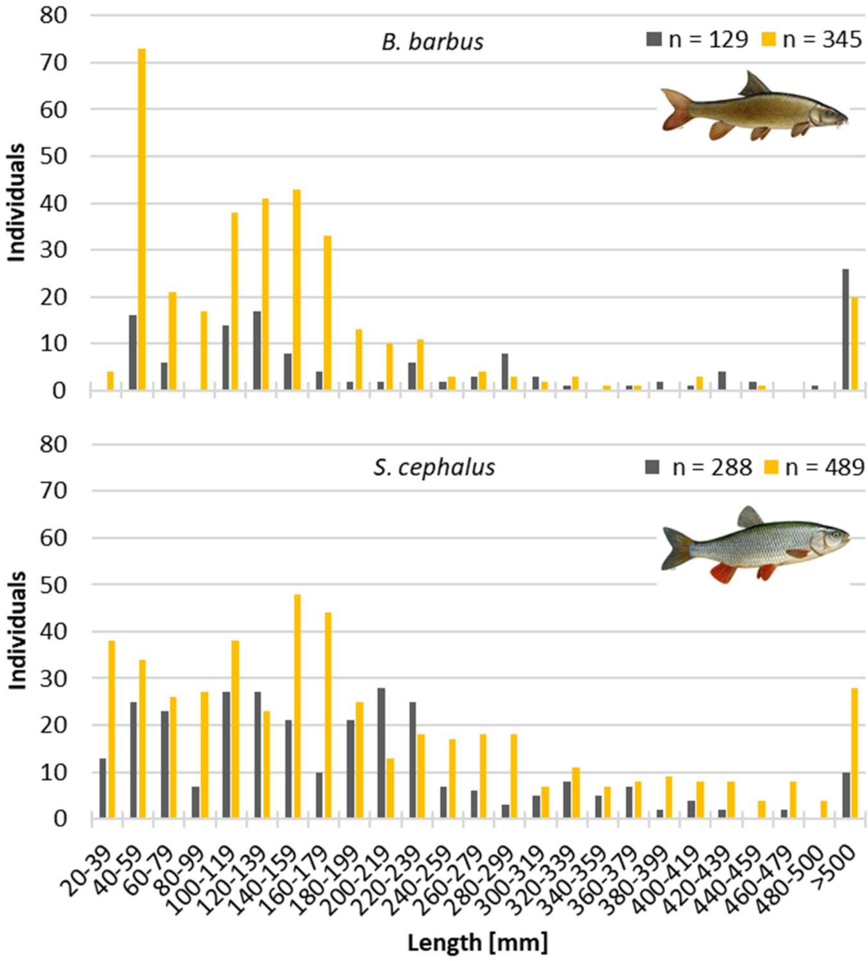


Figure 45: Population structure of B. barbus and S. cephalus in River Traun (grey: upstream of TF; gold: downstream of TF).

In total, 777 individuals of *S. cephalus* were caught (Figure 45). Downstream of LT, the 0+ class is underrepresented; the 1+ class is documented, but individuals with a TL of 240 to 320 mm occur in low numbers. Sufficient adult fish upstream of TF indicates enhanced reproduction potential. Downstream of TF, the population structure is in a similar but slightly better state; juveniles occur in a comparable distribution, and the higher numbers of adult individuals, especially specimens of > 500 mm, secure the natural reproduction ability.

The population structure of *A. bipunctatus* is in a near-natural state in its natural distribution area downstream of TF, while upstream of TF, the species is missing (Figure 46). All age groups are present, of which the 0+ generation is dominant. In total, 1,128 individuals were caught during the investigation. A high share of adult individuals secures the natural reproduction potential.

P. phoxinus is completely missing upstream of TF besides one individual, where the species is listed as dominant (Table 7). Among the 319 individuals downstream of TF, all age groups are present, but juvenile fish are underrepresented (Figure 46).

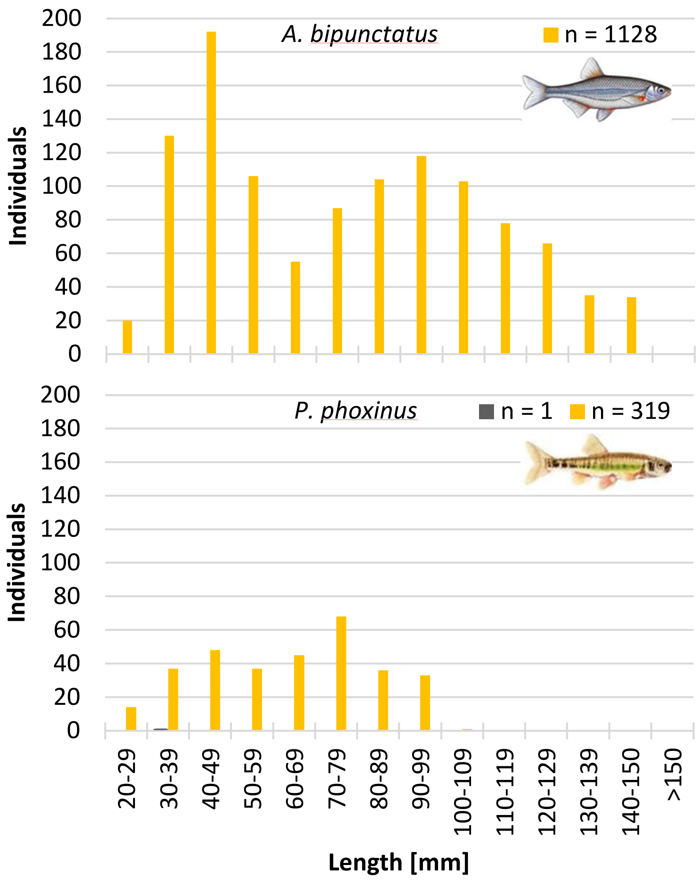


Figure 46: Population structure of A. bipunctatus and P. phoxinus in River Traun (grey: upstream of TF; gold: downstream of TF).

5.3.4 Traun: Comparison of fish metrics in hydrologically impacted and unimpacted stretches

Comparing stock data at riverbanks shows that the biomass in unimpacted parts of the river is significantly higher than in impoundments or residual water stretches at sites Gmunden, Traunfall, Kemating, and Stadl-Paura (Figure 47). In all sites, higher abundances were detected in the unimpacted parts of the river. Furthermore, the number of species is also higher in the free-flowing stretches of all investigated stretches except for site Stadl-Paura. It is particularly noticeable that salmonid species occur in very low densities and biomasses throughout the investigated sites.

Exceptions and irregularities from the general observations mentioned above are found in the site Danzermühl: the abundance per 100 m is approximately equal, but the biomass in the impoundment is 27 kg/ha, 25 kg/ha more than in the unimpacted area. The biomass mainly consists of *S. cephalus* being sampled with the hand anode in rip rap bank habitats on the outer bank and vegetation-covered inner bank. In site 3, the number of occurring species is extremely low, as are abundance and biomass; also, Salmonidae are absent, and *B. barbus* is the sole documented species in the impoundment. At Kemating, *A. bipunctatus* has a significant impact on the abundance (> 70 %) and biomass (> 40 %) of the unimpounded section, while the only verified salmonid species is *S. trutta*. The site of Stadl-Paura shows similar fish abundance between 1,500 and 1,800 Ind./100 m in the free-flowing and impounded stretches, but minimal density in the residual water, which is unconfirmed for biomass. The completely free-flowing site of Lambach, the abundance (> 8,500 Ind./100 m) and species number (14) reach maxima, predominated by *A. bipunctatus, B. barbus,* and *P. phoxinus*, which make up most of the biomass.

	1 Gmunden				2 Danzermühl				3 Steyrermühl			
	Ind/100m		kg/ha		Ind/100m		kg/ha		Ind/100m		kg/ha	
Species												
A. mento	157	-	<1	-	9	23	<1	1	-	-	-	-
B. barbus	43	4	<1	<1	39	7	<1	<1	10	1	<1	<1
C. gobio	62	-	<1	-	15	-	<1	-	-	-	-	-
E. lucius	1	-	1	-	-	<1	-	3	-	-	-	-
O. mykiss	21	-	9	-	<1	4	<1	4	-	-	-	-
P. fluviatilis	98	1	2	<1	7	-	<1	-	10	-	<1	-
R. rutilus	198	1	3	<1	-	-	-	-	-	-	-	-
S. trutta	23	-	1	-	-	-	-	-	-	-	-	-
S. cephalus	656	66	57	<1	59	93	1	17	48	-	1	-
T. thymallus	2	-	<1	-	1	<1	<1	<1	-	-	-	-
Hybrid	6	-	1	-	-	-	-	-	-	-	-	-
Total	**1266**	**73**	**75**	**<1**	**130**	**127**	**2**	**27**	**69**	**1**	**1**	**<1**
Species	**11**	**4**	**11**	**4**	**7**	**6**	**7**	**6**	**3**	**1**	**3**	**1**

	4 Traunfall				5 Kemating				6 Stadl-Paura						7 Lambach	
	Ind/100m		kg/ha		Ind/100m		kg/ha		Ind/100m			kg/ha			Ind/100m	kg/ha
Species																
A. bipunctatus	1750	160	3	<1	2301	183	12	1	748	422	-	<1	<1	-	3481	21
A. mento	67	-	<1	-	19	-	<1	-	-	-	-	-	-	-	-	-
B. barbatula	7	-	<1	-	57	8	<1	<1	-	8	-	-	<1	-	147	<1
B. barbus	59	-	2	-	332	17	5	<1	25	109	4	2	1	<1	1705	16
C. gobio	47	4	<1	<1	38	-	<1	-		-	-	-	-	-	111	1
E. lucius	-	-	-	-	-	-	-	-		-	6		-	1	1	1
G. gobio	-	-	-	-	-	-	-	-	4	117	-	<1	<1	-	156	3
H. hucho	-	-	-	-	-	-	-	-	<1	-	-	1	-	-	-	-
L. leuciscus	-	-	-	-	-	1	-	<1	-	25	-	-	<1	-	-	-
O. mykiss	6	1	1	<1	-	-	-		-	-	-	-		-	10	<1
P. fluviatilis	18	1	<1	<1	1	1	<1	<1	1	30	12	<1	<1	<1	16	<1
P. phoxinus	624	-	<1	-	202	50	1	<1	528	45	-	<1	<1	-	2411	4
P. marmoratus	176	-	<1	-	26	33	<1	<1	18	34	-	<1	<1	-	142	1
P. parva	-	-	-	-	-	-	-	-	-	-	-	-		-	15	<1
R. meidingeri	-	-	-	-	-	-	-	-	-	18	-	-	<1	-	-	-
R. rutilus	-	5	-	<1	-	-	-	-	-	-	-	-	-	-	-	-
S. trutta	10	-	1	-	20	-	1	-	1	-	-	1	-	-	33	1
S. cephalus	179	53	6	3	288	133	9	<1	469	704	15	63	9	7	302	4
T. thymallus	1	-	<1	-	-	-	-	-	1	1	-	1	<1	-	1	<1
Total	**2942**	**223**	**13**	**4**	**3285**	**427**	**30**	**1**	**1795**	**1512**	**38**	**68**	**11**	**8**	**8533**	**52**
Species	**12**	**6**	**12**	**6**	**10**	**8**	**10**	**8**	**10**	**11**	**4**	**10**	**11**	**4**	**14**	**14**

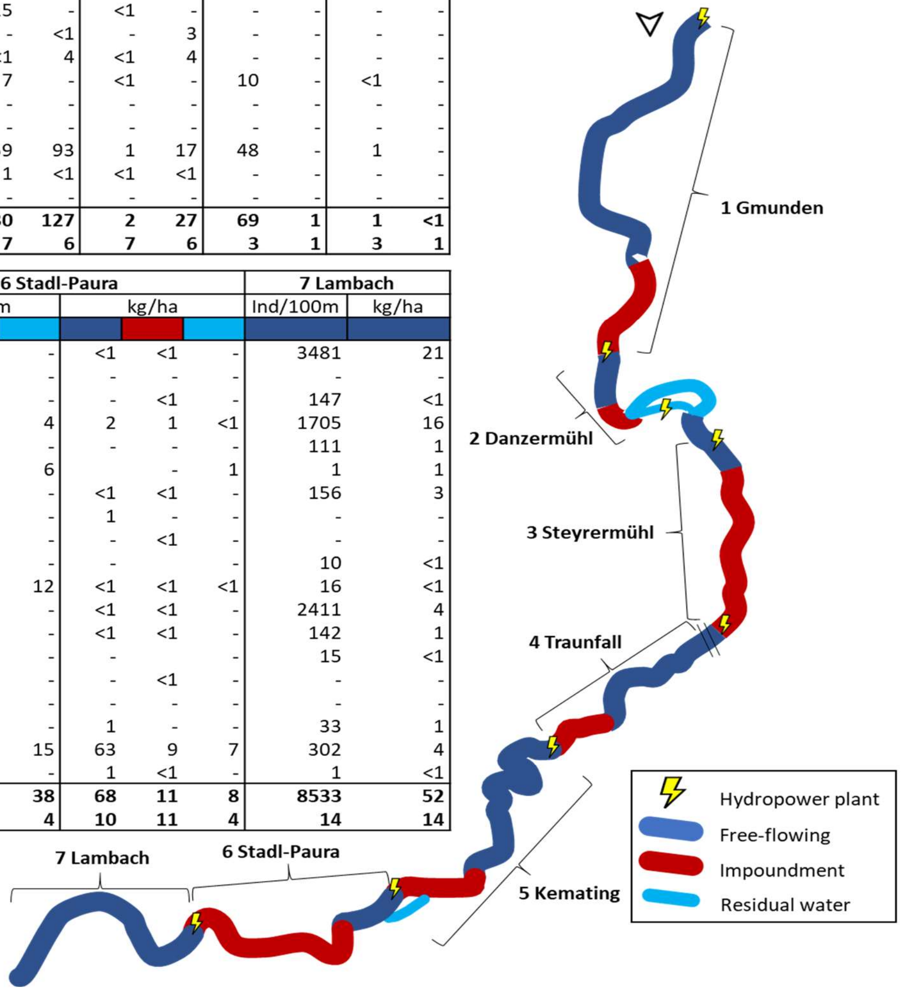


Figure 47: Comparison of fish density (Ind/100 m) and biomass (kg/ha) in free-flowing-/ impoundment- and residual water stretches of River Traun (for better comparability stock estimates are solely based on sampled riverbank-strips).

5.3.5 Alm: Catch numbers, species distribution, abundance, and biomass

In River Alm, eight species with 637 individuals were caught, of which 51 % belong to the family of Salmonidae (Table 8). Besides *L. lota*, five out of six indicator species were documented. *C. gobio* occurs in a relatively high density when compared to the remaining species. The *P. phoxinus* abundance of 189 Ind/ha is attributable to a swarm sampled in one strip downstream of the River Laudach estuary. Further, only a few specimens of the dominant species *B. barbatula* and *T. thymallus*, one of the eight subdominant species, and none of the two rare species from the reference fish were detected. Rainbow trout (15 kg/ha) and brown trout (14 kg/ha) account for most of the total biomass of 35 kg/ha. However, the abundance and biomass level, especially of the native salmonid species *S. trutta* and *T. thymallus,* is deficient for the hyporhithral character of the river. The biomass KO-criterion set by the FIA of 50 kg/ha is clearly not met in River Alm.

Table 8: Reference fish assemblage, total catch (n), species distribution (%), abundance (Ind/ha) and biomass (kg/ha) at the River Alm.

Species	Ref.	n	%	Ind/ha	kg/ha
Alburnoides bipunctatus	s	-	-	-	-
Barbatula barbatula	d	14	2	70	<1
Barbus barbus	s	-	-	-	-
Chondrostoma nasus	s	-	-	-	-
Cottus gobio	d	187	29	323	3
Eudontomyzon mariae	r	-	-	-	-
Gobio gobio	s	-	-	-	-
Hucho hucho	s	-	-	-	-
Leuciscus leuciscus	s	-	-	-	-
Lota lota	d	-	-	-	-
Oncorhynchus mykiss		206	32	79	15
Perca fluviatilis	r	-	-	-	-
Phoxinus phoxinus	d	43	7	189	<1
Rutilus rutilus		1	<1	<1	<1
Salmo trutta	d	168	26	73	14
Squalius cephalus	s	1	<1	<1	<1
Telestes souffia	s	-	-	-	-
Thymallus thymallus	d	17	3	10	3
Total	16	637	100	744	35

5.3.6 Alm: Population structure of selected fish species

The population structure of *O. mykiss* is in a near-natural state with a dominant 0+ age class (Figure 48). The gap between the 0+ and 1+ age class seems to merge in River Alm. The 1+ and older generations are in good condition with a high reproduction potential, resulting in a self-sustaining *O. mykiss* population in River Alm. However, on-site observations of the non-natural origin of substantial parts of the adult rainbow- and brown trout were made.

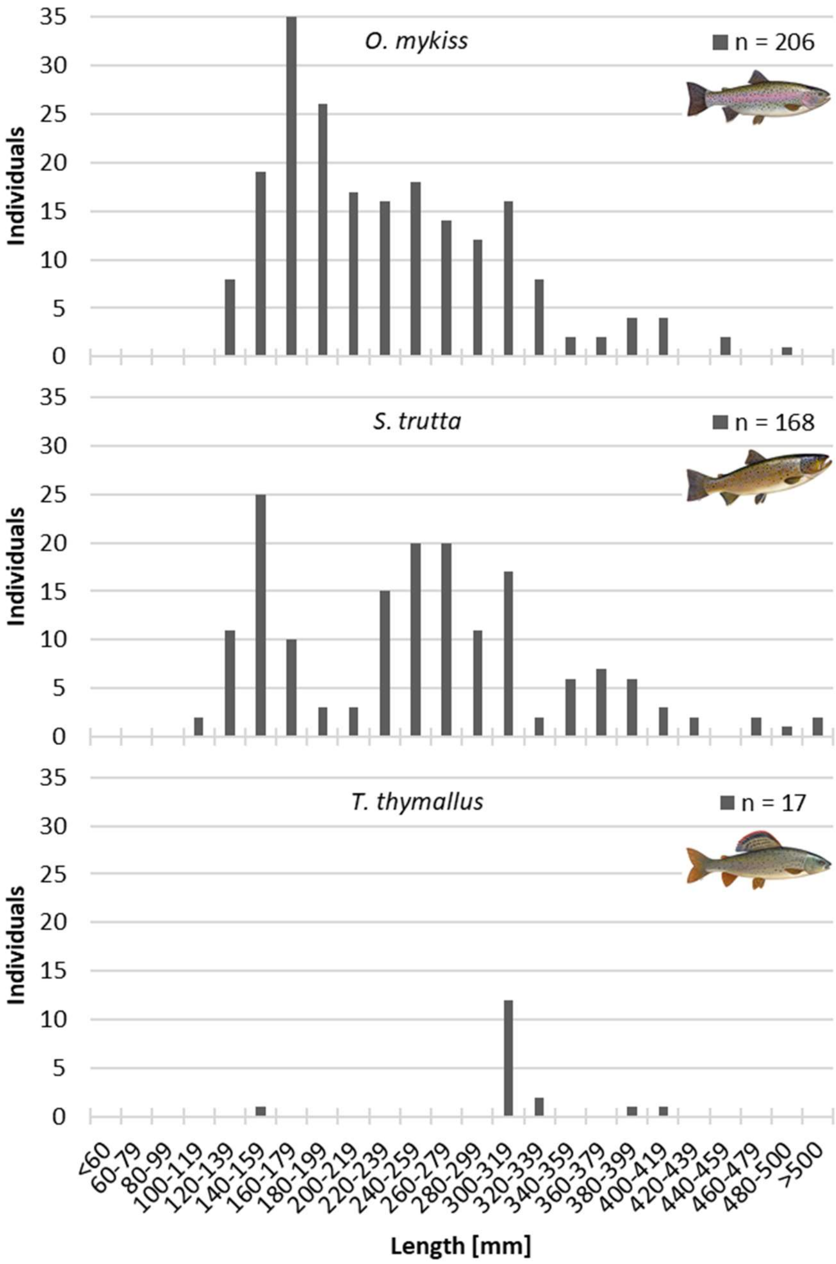


Figure 48: Population structure of O. mykiss, S. trutta, and T. thymallus in River Alm.

The population structure of *S. trutta* is in a good state overall (Figure 48). All age groups are present, yet the 0+ age class is slightly underrepresented. The 1+ generation is particularly strong pronounced in River Alm. Also, the relatively high number of adult brown trout ensures the natural reproduction of the species. The population structure of *T. thymallus* is heavily disturbed in River Alm (Figure 48). The 0+ and 1+ generations are almost entirely missing. Most adult graylings are between 300 and 320 mm in TL. The reproduction potential is very low.

5.3.7 Ager: Catch numbers, species distribution, abundance, and biomass

In River Ager, ten species and 456 fish were documented in total, of which 31 % were identified as *S. cephalus*, 21 % as *B. barbus,* and *T. thymallus* each (Table 9). The remaining twelve species in River Ager show lower shares than 10 %. All four dominant, six out of ten subdominant, and two out of 14 rare species were proven. One individual of the dominant *C. nasus* was caught but is attributed to stocking measures. Also, one individual of the rare and endangered *R. meidingeri* was identified during quantitative sampling.

The total abundance of 1,556 Ind/ha and biomass of 169 kg/ha have been calculated in River Ager. The dominant species *A. bipunctatus*, *B. barbus*, and *S. cephalus* - together with *P. phoxinus* - are the most abundant; the main biomass forming species are *B. barbus* (74 kg/ha) and *S. cephalus* (61 kg/ha). Furthermore, the *T. thymallus* biomass of 20 kg/ha is the highest value recorded in the 2019 sampling campaign across all investigated rivers. On the one hand, more graylings were caught in the Ager than in all sites at the River Traun combined. On the other hand, the length-frequency diagram of *T. thymallus* reveals that the population consists of one-third of juveniles and a healthy distribution of adult fish (Figure 49). The biomass of the remaining species in River Ager does not exceed 5 kg/ha.

Table 9: Reference fish assemblage, total catch (n), species distribution (%), abundance (Ind/ha) and biomass (kg/ha) at the River Ager.

Species	Ref.[1]	n	%	Ind/ha	kg/ha
Abramis brama	r	-	-	-	-
Alburnoides bipunctatus	d	39	9	531	3
Alburnus alburnus	s	-	-	-	-
Aspius aspius	r	-	-	-	-
Barbatula barbatula	s	2	<1	17	<1
Barbus barbus	d	94	21	231	74
Chondrostoma nasus	d	1	<1	1	<1
Cobitis elongatoides	r	-	-	-	-
Cottus gobio	s	4	1	14	<1
Esox lucius	r	-	-	-	-
Eudontomyzon mariae	r	-	-	-	-
Gobio gobio	s	-	-	-	-
Hucho hucho	r	1	<1	<1	<1
Leuciscus leuciscus	s	16	4	18	2
Lota lota	s	-	-	-	-
Oncorhynchus mykiss		21	5	16	5
Perca fluviatilis	r	-	-	-	-
Phoxinus phoxinus	s	35	8	473	1
Rhodeus amarus	r	-	-	-	-
Rutilus meidingeri	r	1	<1	<1	<1
Rutilus rutilus	r	-	-	-	-
Salmo trutta	s	4	1	8	2
Salmo trutta lacustris	r	-	-	-	-
Scardinius erythrophthalmus	r	-	-	-	-
Squalius cephalus	d	140	31	166	61
Telestes souffia	s	-	-	-	-
Thymallus thymallus	s	98	21	79	20
Tinca tinca	r	-	-	-	-
Vimba vimba	r	-	-	-	-
Total	28	456	100	1,556	169

[1] (Petz-Glechner et al., 2007)

5.3.8 Ager: Population structure of selected fish species

Salmonid species

In River Ager, the population structures of *O. mykiss* and *S. trutta* are severely deficient (Figure 49). In both cases, the juvenile stage is completely missing, the older generations are either highly underrepresented (*O. mykiss*), or only single individuals occur (*S. trutta*), which reduces the natural reproduction potential to a minimum. Again, several individuals were identified as hatchery fish. The population structure of *T. thymallus* in River Ager is slightly disturbed (Figure 49). The individuals from the underrepresented 0+ age class were mainly caught in the residual water stretch, and the cohorts with a TL between 200 and 300 mm are missing. Adult graylings with a TL > 300 mm are well represented. It is particularly noticeable that about two-thirds of all 0+ graylings were identified within one strip in the residual water stretch of River Ager, all with a TL of < 200 mm.

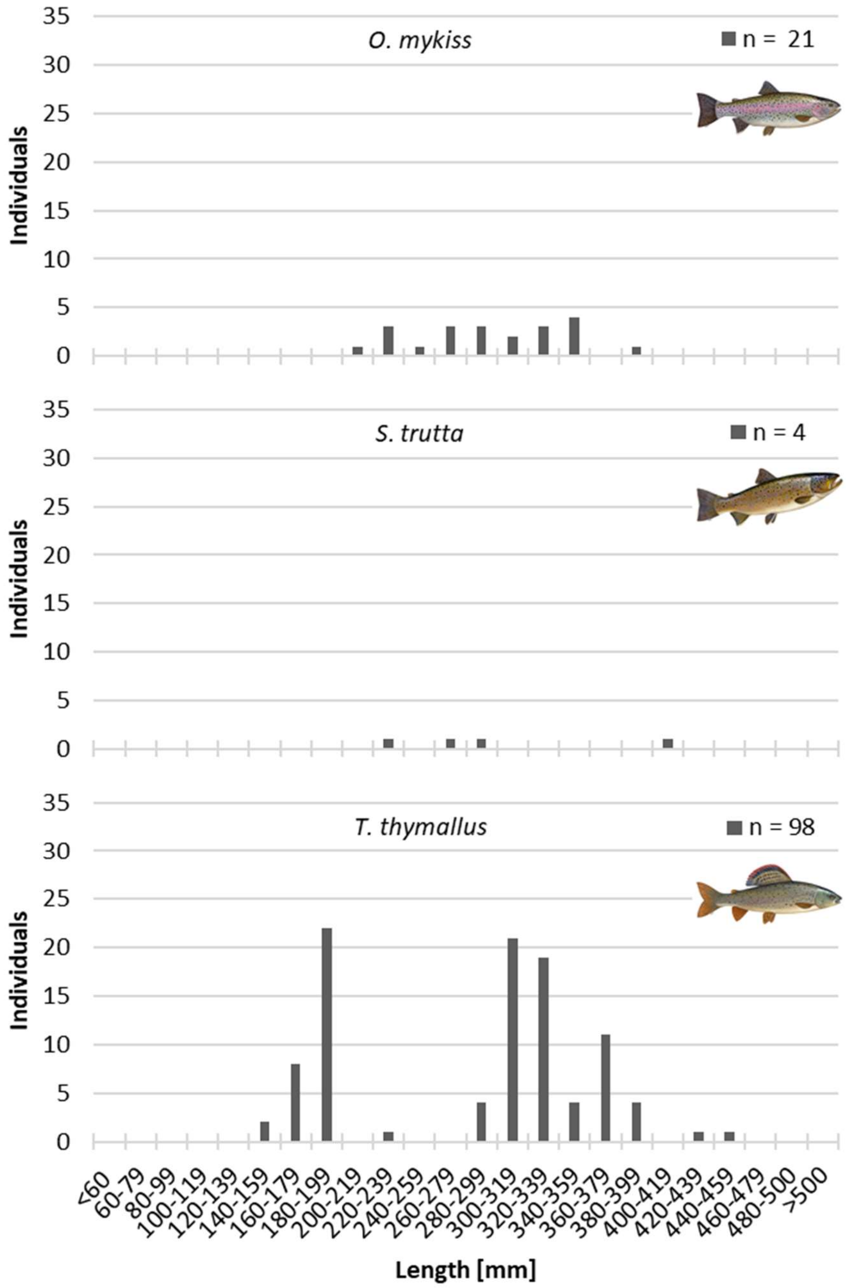


Figure 49: Population structure of O. mykiss, S. trutta, and T. thymallus in River Ager.

Cyprinid species

The population structure of *B. barbus* and *S. cephalus* in River Ager is shown in Figure 50; *A. bipunctatus* and *P. phoxinus* are displayed in Figure 51. The population structure of *B. barbus* is characterized by a relatively high number of individuals with a TL of > 500 mm, increasing the reproduction potential. However, the limited preproduction success is apparent in the underrepresentation of juveniles, as 18 of the 94 specimens are < 300 mm.

The population structure of *S. cephalus* is dominated by individuals > 240 mm and the near absence of the 0+ and 1+ generations. Around 87 % of the 144 individuals have a TL between 240 and 440 mm, showing a good reproduction potential but low success.

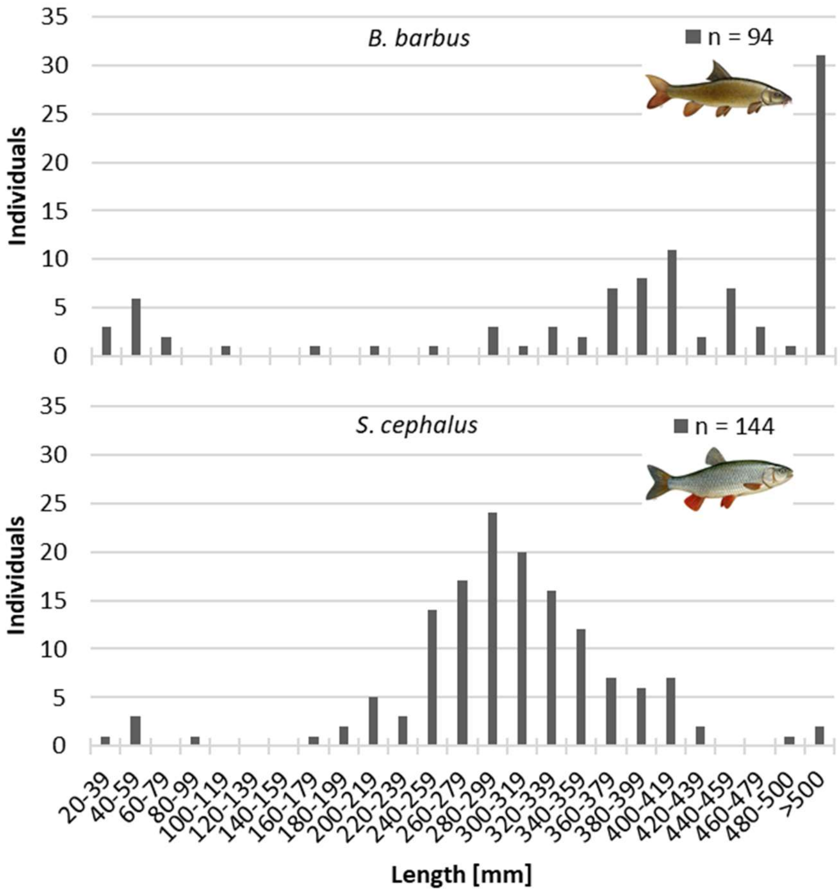


Figure 50: Population structure of B. barbus and S. cephalus in River Ager.

The population structure of *A. bipunctatus* shows that all age groups are present. The 0+ generation, however, is heavily underrepresented.

The *P. phoxinus* population in River Ager consists of all age classes and must be classified as near natural.

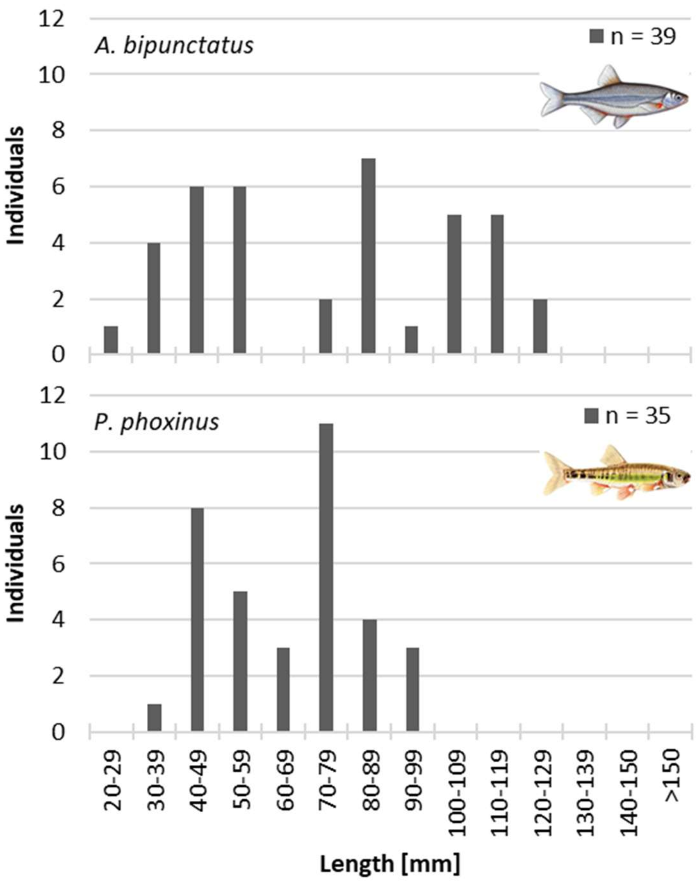


Figure 51: Population structure of A. bipunctatus and P. phoxinus in River Ager.

5.3.9 Alm and Ager: Comparison of fish metrics in hydrologically impacted and unimpacted stretches

Comparing hydrologically unimpacted and impacted river stretches revealed higher or significantly higher biomasses in the free-flowing parts of both rivers (Table 10). In River Alm, eight species are documented in the residual water stretch compared to the unimpacted (five species) and impounded areas (four species). The proximity of the residual water stretch to the River Traun should be noted here, which results in a higher number of species. However, in most cases, there are single individuals of, e.g., *R. rutilus*. *P. phoxinus*, and *S. cephalus* that occur here. The highest biomass of 21 kg/ha is proven in the free-flowing section but is ~ 30 % lower in the residual water stretch. *S. trutta* prefers the unimpacted river over residual water and impoundments. The same is not observed for *O. mykiss*, as the biomass is slightly higher in residual water stretches than in the free-flowing part. It is generally emphasized that the biomass is very low, regardless of the hydrological impact.

In River Ager, the highest species number and biomass are in the free-flowing part, and the lowest in the HPP outflow (2 kg/ha biomass out of four species) were documented. The depth condition in the HPP outflow suggests that sampling has been challenging to conduct and that the indicated biomass may not reflect the actual condition. The main biomass-forming fish species in the free-flowing section are *S. cephalus, B. barbus*, and *T. thymallus*. The biomass of the latter was detected almost entirely in the unimpacted stretch, whereas the species is almost missing in the hydrologically impacted areas. In the residual water stretch, *S. cephalus* accounts for more than 75 % of the total biomass.

Table 10: Comparison of biomass (kg/ha) in free-flowing-/ impounded-/residual water stretches and HPP outflow of rivers Alm and Ager.

	Alm			**Ager**		
Species	Free-flowing	Impound-ment	Residual water	Free-flowing	HPP outflow	Residual water
Alburnoides bipunctatus	-	-	-	1	-	2
Barbatula barbatula	-	-	<1	-	-	<1
Barbus barbus	-	-	-	74	-	<1
Chondrostoma nasus	-	-	-	<1	-	-
Cottus gobio	1	<1	1	<1	-	<1
Hucho hucho	-	-	-	<1	-	-
Leuciscus leuciscus	-	-	-	2	-	-
Oncorhynchus mykiss	7	<1	8	5	<1	<1
Phoxinus phoxinus	<1	<1	<1	<1	-	1
Rutilus meidingeri	-	-	-	<1	-	-
Rutilus rutilus	-	-	<1	-	-	-
Salmo trutta	12	<1	2	1	<1	-
Squalius cephalus	-	-	<1	45	1	15
Thymallus thymallus	1	-	2	20	<1	<1
Total biomass	21	<1	14	148	2	19
Species number	5	4	8	12	4	8

6 Discussion

In this thesis, three research questions were examined with seven hypotheses in total. In the beginning, it is evaluated how anthropogenic impacts and the climatic conditions lead to habitat degradation over time. In the second objective, specific changes to the natural fish fauna are discussed. Further, the fish fauna deriving deficits from the 2019 sampling campaign are identified, future challenges to the fish fauna are addressed, and restoration priorities are discussed.

6.1 Changes in the Traun catchment area in the context of anthropogenically induced impacts

Records of fishery statistics from the **19th century** reflect the typically high **abundance of the dominant species** *C. nasus*, *B. barbus*, and *T. thymallus* in the Traun catchment, supporting a thriving commercial fishery (chapter 5.2.1). Downstream of TF, the catch figures of *S. trutta*, *H. hucho*, and *E. lucius* in the 18th and 19th centuries indicate secondary importance to commercial fisheries as the species mentioned above. In the 20th century but especially after World War II, commercial fisheries lost in importance, as shown by the sales figures of the Linz fish market (Wacha, 1956). Thus, the River Traun and its tributaries went from being one of the richest sources of wild fish in the country to a river with dwindling fish stocks, validating the first part of **hypothesis H1** "Historical fish abundance decreased, native species disappeared, and allochthonous species increased over time" for the period prior to quantitative fish stock assessments. The formerly high densities of salmonid and cyprinid species and their decline are also documented in other alpine rivers like the River Enns (Ratschan et al., 2011) or the River Salzach (Schmall & Ratschan, 2011).

The impacts with the severest effects on the fish fauna are **morphological changes**, caused mainly by **river engineering** and **HPP construction**. According to Haidvogl et al. (2015) and Jungwirth et al. (2003), the loss in both occurrence and abundance started with river engineering measures beginning in the middle ages and intensifying in the following centuries but especially in the industrial age. The conversion of former floodplain and retention areas into agriculturally land or flood protection dikes caused habitat loss, leading to a drastic decline, particularly in phytophilous fish species (Jungwirth et al., 2003; Spindler & Chovanec, 1997). Despite their significantly different life forms, *P. phoxinus*, *E. lucius*, and *T. tinca* require varying bank and depth structures for all development stages from egg to adult. Thus, river engineering measures modify vital bank habitats morphologically and accelerate the disappearance of key species (Bless, 1992; Kottelat & Freyhof, 2007).

In the investigated rivers, the construction of HPPs of different sizes started in the 19th century and is primarily concentrated in the hyporhithral (grayling region), allowing efficient energy production by using the high gradient in these river sections (Table 2). The HPPs regularly operate with water level fluctuations in sunk and surge mode, exposing all life stages of fish to constant hydraulic stress, desiccation of spawning pits, and littoral habitats (Hayes et al., 2019; Spindler & Chovanec, 1997).

With several morphologically strongly and moderately modified river sections in the study area according to BMLRT (2020b), fish density and biomass are lower in these sites compared to the free-flowing parts (chapter 5.3.4). Reduced flow velocities change the substrate composition and therefore alter the spawning grounds for lithophilic species, which are the prerequisite for successful reproduction and the formation of a self-sustaining population (Jungwirth et al., 2003; Spindler & Chovanec, 1997; Walder, 2009).

The establishment of dams, weirs, and embankments causes a **longitudinal and lateral interruption of the water continuum**, hindering the fish in their natural migrations due to the missing fish passes (Jungwirth et al., 1989; chapter 5.1.3). The time gap between the construction of the HPPs and their fish passes ranges between several decades and a century (Table 2). Entering a fish pass may require the swarm structure to break up during the migration, leading to behavioral barriers as the facilities are accepted only by a fraction of the migrating individuals. The effect is particularly pronounced when migrating from the Danube into a comparatively small fish pass and concerns mainly medium- to long-distance migratory species (Zauner et al., 2014). With the construction of the weirs Kleinmünchen/Traunwehr, Traun-Pucking, and Marchtrenk from 1978 to 1984, the access of the dominant species (*C. nasus*, *B. barbus*), subdominant species (*A. brama*), and rare species (*L. idus, V. vimba*) to and from the Danube mainly was denied and consequently disappeared in the Lower Traun catchment (chapter 5.2.1). Many fish passes were or are not in conformity with the normative requirements and represent a minor improvement to the longitudinal migration, as is the case in River Traun. Zauner et al. (2014) describe the dimensioning and positioning of the vertical slot pass at the HPP Kleinmünchen/Traunwehr largely corresponds to the specifications of the FAH guidelines, but the accessibility and findability of the fish pass might be reduced for both weak swimmers and larger species by the height difference between the riverbed ramp and the fish pass. At HPP Lambach, neither of the two bypass channels meet the requirements of the FAH guidelines. The vertical slot section of the fish pass at HPP Kemating (new construction 2016) is unsuitable for large and small fish species, expecting a significant reduction in the migratory capacity. Where space is available for extensive measures, near-natural side- or bypass channels must be considered, such as at the HPP Kleinmünchen/Traunwehr, enhancing valuable aquatic and semi-aquatic habitats as improving the passability and acceptance by migratory species (Zauner et al., 2014).

The question of **downstream passability** is also of increasing importance. As already mentioned in chapter 5.3.1, stagnant water fish species are absent downstream of HPP Gmunden, which raises the question of the downstream passage functionality on the one hand and whether the fish stock in LT corresponds to the original conditions on the other hand. During the last fish stock survey of LT in 2012, *B. barbatula*, *P. phoxinus,* and *V. vimba* were not detected in LT, excluding that fish descent from the lake, leaving the immigration from areas further downstream as the only option for natural repopulation of the river stretch (Gassner et al., 2013). As described in chapter 5.1.3, the fish lift at HPP Gmunden is deficient in the upstream migration direction for salmonids and *B. barbus*. The design of the fish lift excludes the downstream migration for fish from LT, leaving the way through the turbines, the weirs gates (9.2 m height), or the open weirs at high discharge events as the only migration routes (Energie AG, 2020). Hence, one of the top priorities is improving existing- and the correct construction of new fish passes in both directions (Brink et al., 2018; O'Hanley et al., 2013). If these two functions are not guaranteed, increased mortality and isolation of fish reaching upper, permanently unsuitable sections will lead to a continuous reduction or weakening of long- and medium-distance migratory species in the entire area such as grayling, barbel, nase, and burbot (Zauner et al., 2014).

The **continuum at River Alm** is interrupted by ten transverse structures in the study area (chapter 5.1.2). While fish passes have been constructed around the barriers further upstream in recent years, the lowest rough ramp (height 2.8 m; river-km 0.9) is impassable for organisms. Thus, causing the absence of all subdominant and rare species in the river's lower reaches and preventing the exchange of fish species between the relatively species-rich River Traun and the relatively species-poor River Alm (Table 9; Ratschan et al., 2020). A HPP with an integrated fish pass is currently under construction, which is expected to restore the continuity with a substantial quantitative and qualitative increase in fish mobility of rheophilic and indifferent species. The anticipated positive effects on the biomass, species composition, and the ecological state of River Alm will benefit the species *A. bipunctatus*, *B. barbus*, *G. gobio*, and *S. cephalus* (Ratschan et al., 2020). However, weirs always represent an incision in fish migration. Even with a guideline-compliant fish pass, only a minor proportion of the fish are usually able to migrate to the newly available river reaches, as the natural migration routes are only restored by the complete deconstruction of the weirs (BMLFUW, 2012; Gumpinger, 2001; Ratschan et al., 2011). In the contexed of fish migration **hypothesis H5,** "Species immigration and exchange are impaired by deficient migration facilities," is validated for all investigated rivers.

The **water quality** of Rivers Traun and Ager was influenced by wastewater input from the paper and cellulose industry starting in the mid-19th century. Although the effect on the rivers was certainly negative, the fish stock in the Ager must have still been excellent at that time (Werth et al., 1978). The water quality improved continuously during the following decades with the construction and commissioning of water treatment plants (chapter 5.1.4). Water contamination affects salmonid stocks directly, but if the oxygen supply is guaranteed, *T. thymallus* has certain tolerances to industrial wastewater but the biomass was probably still lower under natural conditions (Kainz, 1992; Uiblein et al., 2000). Sensitive species to water quality degradation such as *L. lota*, *C. nasus*, *E. mariae*, *B. barbatula*, *L. leuciscus*, *A. bipunctatus*, and *T. souffia* experienced a severe population decline or are currently absent in at least one of the Lower Traun sites (chapter 5.2.1). Nowadays, the most important source of pollution is less industrial wastewater and sewage discharge from treatment plants, but rather the diffuse nutrients load from agriculture (BMLRT, 2020b).

Overall, morphological river regulation, the construction of HPPs and weirs, the interruption of the river continuum, and water pollution severely impacted the local fish fauna. Therefore, **hypothesis H7,** "Aquatic habitat alterations by river engineering, hydroelectric power use, water pollution, and water temperature increase are responsible for changes in fish metrics," is accepted.

Aside from influences related to the hydromorphological and chemical conditions, the **water temperature** is an essential factor for aquatic organisms' specific range and tolerance (Lampert & Sommer, 2007). The timing of migration and reproduction, age at maturity, age at juvenile migration, growth, survival, and fecundity are controlled and dependent on temperature changes (Crozier & Hutchings, 2014). The increase in temperature in the rivers Ager and Traun was about 2.4°C between 1976 and 2010 (Melcher et al., 2013; Pletterbauer, 2009). Before thermal emissions, the water temperature regularly reaches up to 22°C in River Ager and 19°C in River Traun with peaks over 25°C (Ager) and 23°C (Traun) during hot summer periods. These values are considered critical for salmonids (Nachtnebel & Haider, 2007). The **temperature requirements for salmonids** are best explained using the example of *T. thymallus* (Jungwirth, 1986, p. 198; Jungwirth, Haidvogl, Moog, et al., 2003; Küttel et al., 2002; Reinartz et al., 2007; Simon et al., 2008; Uiblein et al., 2000): The spawning migration begins a few days after snowmelt at water temperatures of 4 to 6 °C, whereas the spawning activity mostly takes place in a temperature range between 7 and 11 °C. The optimal temperature for egg/embryonic development is between 6 and 14°C. Below five °C and above ~ 15 °C, the hatching success decreases significantly, approaching zero at water temperatures below three °C and above 16 to 20 °C. Additional thermal loads and the climate change-induced temperature increase shift in spawning migration and activity on the one hand and stretch the temperature range to an intolerable level on the other. The new environmental conditions become limiting factors for salmonids and will likely favor eurytopic species like *S. cephalus* and *B. barbus* (Geist, 2016; Mueller et al., 2020). The distribution expansion and their reproductive success are already observed in the upstream shift of the fish regions (chapters 5.1.3 & 5.1.5). Regarding fish growth, 0+ and 1+ grayling show optima at 15 to 17°C, whereas the upper critical temperature for adult specimens is 18 and 24°C (Jungwirth, 1986; Küttel et al., 2002). Increased summer water temperatures might have beneficial effects on fish growth, but the long-term exposure of oligo-stenothermic species leads to increased oxygen consumption and eventual dietary cessation (Binner, 2007; Ficke et al., 2007; Reinartz et al., 2007). The increased temperatures of the rivers as multiple lake outflows are one possible cause for the weak grayling populations in the rivers Ager and Traun, causing stagnation in reproduction.

With rising summer water temperatures in alpine rivers, the spread of new **diseases** like T. bryosalmonae (PKD) is more likely over the following years as climate change may alter host-parasite dynamics by changing transmission opportunities and host susceptibility (Ficke et al., 2007). Temperatures above 15°C accelerate the outbreak of PKD, which are recorded constantly for 2.5 months in River Traun near Wels in 2019 (Hari et al., 2006; HD OOE, 2020; Lewisch et al., 2018). The PKD is already documented upstream of LT and LH (Borgwardt et al., 2020; Borgwardt, personal communication, 2020; Lewisch et al., 2018). The disease can cause high mortality rates in affected brown trout stocks, especially for juveniles (Gorgoglione et al., 2016). PKD was identified in the sample of one grayling individual in the 2019 survey, but not in adult brown trout, indicating that the low number of brown trout juveniles is probably caused by other causes than PKD (chapter 5.3.3).

The change in climatic conditions and thus water temperature affect species composition and lead to a reduction in salmonid and loss of cyprinid species. Therefore, **hypothesis H7,** "Aquatic habitat alterations by river engineering, hydroelectric power use, water pollution, and water temperature increase are responsible for changes in fish metrics," is accepted for rivers Traun and Ager. However, in River Alm, the water temperature increased, but cyprinids are not advanced so far, leading to the rejection of **hypothesis H7**.

6.2 Predation pressure

The predation pressure of piscivorous birds on native fish species is a highly controversial topic of public interest. In recent years, however, the rapid increase in the number of cormorants throughout Europe has become a central issue for recreational fishing. According to Jungwirth et al. (1995) and Kainz (1994), cormorants cause a dramatic quantitative decline in the salmonid population of rhithral rivers. Especially the grayling, due to its behavior and winter habitat preference, has been decimated to such an extent that a stock collapse is becoming apparent (Jungwirth et al., 1995; Kainz, 1994). In the study area, the predation pressure of *P. carbo sinensis* on the local fish stock is especially distinctive considering *T. thymallus* and *P. fluviatilis* (Grohmann in prep.). At least 30 % of the tagged grayling are being removed by the cormorant in rivers Traun and Alm, while at the River Ager, the percentage is somewhat lower at 20 %. However, the actual figures are probably much higher (Grohmann in prep.). Individuals between 200 and 280 mm are mostly missing up- and downstream of TF in River

Traun, indicating predation by *P. carbo sinensis* (Figure 12). According to the preliminary results from cormorant monitoring, the average retrieved grayling measures 269 mm (Table 4). Considering the current minimal salmonid stock in the investigated rivers, the additional hunting pressure of the cormorant represents a further population-reducing factor and should be closely monitored in the future. By far the most individuals were taken out of the stocked *O. mykiss*, where the cormorant benefits from the additional and likely easy to catch specimens, as the size and range of the preyed rainbow trout coincide with the size classes of hatchery fish (Table 4). The predation pressure on cyprinid species *B. barbus,* and *S. cephalus* is not pronounced to the same extent. The absolute retrieved number and the feeding ratio of cyprinids are < 10 % in all rivers, indicating that demographic deficits are not attributable to cormorant predation. The birds do not feed on the most abundant species in this case (Table 4).

During the survey in 2019, the graylings were caught most frequently in midstream mesohabitats in the free-flowing stretches of River Traun and rarely in impoundments[5] (Table 10; Figure 47). As shown in Figure 12, the cormorant's selectivity for *T. thymallus* with a TL of > 200 mm does not correspond to the proven population structure in the River Traun. The fact that not more subadult specimens have been preyed on could be related to the relatively shallow and covered juvenile habitats found mainly in the residual water stretches of Stadl-Paura and Ager, complicating the hunt of the cormorant (chapters 5.3.3 & 5.3.8). The additional pressure of *P. carbo sinensis* on wild salmonid stocks leads to recovery stagnation of local stocks. However, the following essential framework conditions in the investigated area must be considered: The designation of the Lower Traun as a bird sanctuary created a **conflict between fishing rights holders and bird conservationists** regarding the cormorant and goosander. The birds are held responsible for the stock decline of the grayling and brown trout by the fishery but are protected in the Europaschutzgebiet "Untere Traun," impeding any possible management measures (LFVOOE, 2021). On the other hand, the species *C. gobio*, *H. hucho*, *R. meidingeri*, and *T. thymallus* are amongst others protected in the Natura 2000 area “Unteres Traun- und Almtal”, which is included the Europaschutzgebiet “Untere Traun” for the most part. An evident influence of the birds on the grayling stock is identified in the

[5] the limitation of the fishing method in impoundments must be considered in the interpretation of the results (chapter 4.2).

preliminary analysis of the predation pressure, giving fishing rights holders cause for concern (chapter 5.1.8). However, predatory birds are not the trigger but rather one of the many multiple stressors in the decline of fish stocks. The main reasons are poor river structure, low-quality spawning areas, inputs of soil and pollutants, and improper management of water bodies (LBV, 2021). Studies in Switzerland have shown that cormorants disproportionately prey or injure graylings (Thiel, 2008). By renouncing to manage cormorants, a substantial grayling decline is tolerated as a result. Suppose the population decline is to be stopped or grayling are promoted, the cormorant must be kept away from sensitive river sections, for example, by non-lethal methods such as netting key fish habitats of the river to reduce the predation pressure. From a legal point of view, the conservation of natural biodiversity and its habitats of both fish and birds is enshrined in EU and state laws. For ecological and biological reasons, it is demonstrably not possible to leave the cormorant unmanaged without adverse effects on fish stocks and fisheries. The question, therefore, is whether cormorants or endangered fish species have priority and whose lobby is more decisive in political and nature conservation decisions at the moment (Thiel, 2008). On the other hand, bird conservation departments claim that shooting cormorants does not affect fish populations because they generally feed on the most abundant fish species in the waters, which was not proven within the scope of this study (LBV, 2021). Like every animal species, the cormorant has a fundamental right to exist and fulfills an ecological function such as regulating the most common fish species (e.g., *P. fluviatilis*), quite to the advantage of rare or fish species important to fisheries (Haimbuchner, 2013). Another, possibly much more target-oriented measure is to fundamentally improve the ecological situation of impacted areas by river restoration measures (chapter 6.3.4; Haimbuchner, 2013). Based on these results, **hypothesis H6,** “Predation pressure by *P. carbo sinensis* reduces the fish stock” is rejected.

6.3 Implications of human-induced changes on the fish coenosis

Considering the climatic and anthropogenic impacts of multiple stressors on the natural fish habitat already discussed in the previous chapters, adverse effects on fish diversity (i.e., the disappearance of original and emergence of allochthonous species) and a disturbed longitudinal distribution are expected. Further, the natural reproduction of many reference species is projected to be minimal, as is the case for quantitative population parameters such as abundance and biomass. In the following, the four points in the lower part of Figure 52 are addressed in detail.

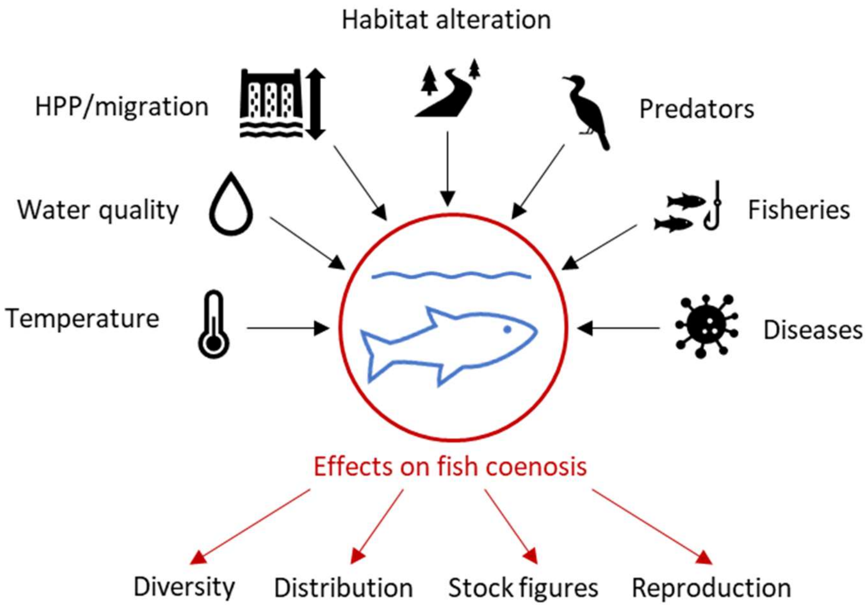


Figure 52: Illustration of the environmental impacts and their effects on central aspects of the fish population in the study area.

6.3.1 Species diversity and distribution over time

The **original fish fauna is subject to a significant change** when comparing historical and recent records, as six species disappeared, and nine new species emerged **from LT to TF** (Table 5). Whether the occurrence of *B. bjoerkna*, *C. elongatoides*, *S. erythrophthalmus*, and *T. souffia* in LT and downstream is based on reliable sources is questionable, as either the habitat requirements as typical stagnant water species are not met in a river, nor are the species found in the reference species occurrence of LT (Gassner et al., 2013; Gassner et al., 2003; Kottelat & Freyhof, 2007). The remaining stock of the dominant species *P. phoxinus* upstream of TF is under high pressure of extinction, as 23 specimens have been recorded in this section in total since 1992, and the population in LT has disappeared recently[6] (Gassner et al., 2013). The high occurrence and predation pressure of *P. fluviatilis* on juvenile *P. phoxinus* is the main reason for their disappearance and failed recent reintroduction projects in LT (Gassner, personal communication; Gassner et al., 2013). The natural repopulation from stocks downstream of

[6] *B. barbatula* disappeared upstream TF (no specimens found in quantitative surveys) and in LT recently (Gassner et al., 2013).

TF is impossible as the TF represents a migration barrier. In order to revitalize the stocks of key species like *A. bipunctatus* or accompanying species like *P. phoxinus* and *B. barbatula* upstream of TF, consideration should be given to the reintroduction of reference species by founder populations from more abundant sites (e.g., Lambach, Alm), in order to avoid the genetic impoverishment of the remaining stocks (Gassner et al., 2013). Also, stocking with large trout must be reduced that do not occur naturally in this density and represent a threat to the already weak or missing populations of *A. bipunctatus* and *P. phoxinus*, species that are reportedly preyed upon by hatchery fish (Kainz, 2010). Even though single individuals of the nase are occasionally evidenced, the unsuccessful re-introduction of *C. nasus* is likely caused by a combination of missing habitat quality, self-establishing stocking material, hydromorphological deficits, and predation pressures piscivorous birds, according to Zauner et al. (2014). Methods for improving the situation are discussed in chapter 6.3.4.

From TF to the Danube estuary, the difference between the species dis- and reappearance is much higher. Out of the 17 initial species, an additional 20 are found since 1992 (Table 5). *A. Anguilla, C. auratus*, and *S. fontinalis* were introduced by intention/mistake or are solitary findings that usually do not survive in the river system. Invasive neozoa *G. aculeatus, L. gibbosus, N. melanostomus, P. semilunaris, and P. parva,* on the other side, are highly tolerant and will likely extend their distribution range in the Traun catchment. *P. semilunaris* is already evidenced in sites Traunfall (2019) and Gmunden (2009). Schmall and Ratschan (2011) confirm the loss of autochthonous species and gain in neozoa or untypical species in the rivers Salzach and Inn. Studies from North America show that the massive spread of *N. melanostomus* leads to the displacement of the native bullhead, at least at the local level (Charlebois et al., 2001). Aggressive behavior regarding competition for food, spawning grounds, nest protection, and refuge prevented reproduction of the bullhead, while at the same time, goby populations increased (Janssen & Jude, 2001). Similar observations are also obtained with *P. semilunaris* (Wiesner et al., 2010). Evidence of parasitic infestations or behavior of alien fauna is found in *P. parva*, directly attacking and injuring larger native fish and changing the fish species and macrozoobenthos composition (Wiesner et al., 2010). From Wörthersee, Carinthia, impairments of net fisheries due to high densities of *L. gibbosus* are reported, which is likely to be introduced in LT and possibly in the Lower Traun in the future (Honsig-Erlenburg & Petutschnig, 2002). A consensus exists that the further spread and exacerbation of invasive species is conceivable in the medium term with the ongoing warming of aquatic ecosystems, even if the severity is currently limited due to their still relatively low densities (Wiesner et al., 2010). Furthermore, the observation was made that many new species downstream of TF are cyprinids, a development that is similarly known from Bavaria (Geist, 2016; Schubert et al., 2018).

Because of species interchange with River Traun, in rivers Ager and Alm, more species are documented in the last decade than before. More species are found in recent times than in former periods, validating the **hypothesis H1** "Fish metrics in the investigated rivers changed over time" for all rivers.

The **current species distribution** allows the statement that the previously described original dominance of autochthonous species is currently missing in the investigated area of River Traun. **Between LT and TF**, 12 out of 22 reference species are missing (Table 7). The dominant species *C. gobio, P. phoxinus, S. trutta,* and *T. thymallus* today account for 11 % of the total catch and < 4 % of the total abundance and total biomass, while *L. lota* is missing entirely. Four of the nine subdominant species, including *A. bipunctatus*, *B. barbatula*, *G. gobio,* and *L. leuciscus*[7], were neither identified during quantitative fish stock surveys in the last 40 years nor the 2012 fish stock survey of LT. These findings lead to the acceptance of **hypothesis H4,** "Species distribution does not correspond to reference conditions." In 2009, the last lake morph of *S. trutta* was identified in site Gmunden; in LT, six individuals were documented in 2012, confirming the vulnerable population in the last years (Gassner et al., 2013). Also, six[8] of the eight rare species are absent upstream of TF. Responsible for the reduction or absence of the species is a combination of factors described in chapter 6.1 and the weak or absent stocks of *P. phoxinus*, *L. lota,* and other species in LT, influencing the occurrence of these species downstream (chapters 5.1 & 5.3).

In the investigated sites **downstream of TF**, more than half of the reference species were not documented. *T. thymallus* accounts for < 4 % of the total catch, abundance, or biomass, while *C. nasus* was not evidenced. In the River Ager, the actual situation is somehow better as both dominant (*A. bipunctatus, B. barbus*, *S. cephalus*) and subdominant species today account for ~ 60 % of the stock. Compared to River Traun, the catch of one nase was achieved, whereby

[7] besides one individual caught downstream of HPP Steyrermühl in 2018
[8] *A. brama, Coregonus sp., E. mariae, R. meidingeri, T. tinca, V. vimba*

all dominant species were detected in River Ager. These values confirm the shifted species composition in the areas described due to habitat changes, which is more pronounced in River Traun than in River Ager. The fish fauna will encounter difficulties in recovering independently from this low level, especially as far as salmonids are concerned, which are affected by the lack of both adult and juvenile individuals. In River Alm, the dominant species account for around two-thirds of the distribution, of which *C. gobio* (29 %) and *S. trutta* (26 %) are the most frequent species. The initially dominant *T. thymallus* is rarely found (3%), whereas *L. lota* is absent. Based on these findings, **hypothesis H4** is validated for the section downstream of TF and River Ager. However, slight deviations from the original conditions lead to the refusal in the case of River Alm.

The obtained data in chapter 5.3 indicates that the HPP Lambach is a bottleneck for migrating fish. The abundance in site 7 is almost twice as high as in any other site further upstream, and migrating reference species from the Danube are largely or entirely missing. The same deficits apply to most of the HPPs in the Lower Traun, some of which show slight to considerable deficits in fish passage, according to Zauner et al. (2014), who also provide proposals for the general improvement of the fish passes. The Federal Ministry of Agriculture, Regions, and Tourism has subdivided planned projects into priority rehabilitation areas according to their urgency. The implementation is not classified as urgent and is partly open in the study area (BMLRT, 2020b).

6.3.2 Implications on quantitative population figures over the last 40 years

The fish stocks underwent significant changes in both absolute and relative **abundance and biomass** in the last 40 years, concerning mainly salmonid species as *T. thymallus* (chapter 5.2.2). Vice versa, the cyprinid share is increasing in abundance and biomass, as *A. bipunctatus* and *P. phoxinus* dominate downstream of TF, while upstream of TF *B. barbus* and *S. cephalus* show the highest shares. These findings lead to the verification of **hypothesis H2** "Species composition shifted from salmonid to cyprinid predominance."

Upstream of LT, the salmonid biomass share is > 80 % in every period, but the absolute biomass decreases steadily, while the abundance share has altered temporally. Compared to the Lower Traun in the family and species compositions, the significant difference might be related to changed reference conditions between LH and LT, where *C. gobio*, *S. trutta*, and

T. thymallus are listed as dominant species. They are much more likely caused by an increase of *O. mykiss* in abundance and biomass share at the expense of *T. thymallus* and *S. trutta*, leading to the rejection of **hypothesis H2.** Also, the disappearance of the burbot in the last decade is of significant importance and should not remain unmentioned.

The increase in the fish metrics of *O. mykiss* is related to the high stocking numbers; however, the species is found in very low densities in the River Traun. The stocking locations and sites with the densest rainbow trout occurrence do not coincide (highest in Gmunden 49 Ind/ha and Lambach 23 Ind/ha; Figure 42). Considering the biomass in the sites up- and downstream of the stocking location, migration to the neighboring sites of Danzermühl and Steyrermühl (< 1 to 5 kg/ha) is not verified (Figure 43). According to Ratschan et al. (2020), all tagged hatchery fish in the scope of the study from 2019 were no longer detected in River Alm during spawning migration monitoring, apart from one individual. The introduced animals disappear from the system within a few months. A similar phenomenon is documented in a study from the U.S., where the annual mortality rate of stocked brown trout was 99.9% (Alexiades & Kraft, 2017).

The **Fish Region Index** (**FRI**) determines the current state of the fish coenosis of a river. It is 5.3 in the “epipotamal large” section from LT to the Ager estuary and 6.1 downstream to the Danube (Haunschmid et al., 2017). The fewer salmonids occur, the higher is the FRI. Values higher than 5.5 indicate a shift from the grayling- to the barbel region. In three investigation sites of ecological studies by Pletterbauer (2009) upstream of TF, which mainly correspond with the sites 1 to 3 in the 2019 survey, FRI values of 5.45, 5.90, and 6.20 were calculated. In conducted fish stock surveys in 2017 and 2018, the values reached 5.90, 5.20, and 5.90 (BMNT, 2019). The reference value of 5.3 is exceeded in almost all cases in this region, proving that the fish species composition has changed slightly towards atypical species for this bioregion, validating **hypothesis H2**. The main impact is the absence of dominant and subdominant species, influencing the FRI by their weighing factors of 10 and 5, respectively (Haunschmid et al., 2017).

The **fish region "epipotamal large"** currently extends to the mouth of the River Ager. The expansion of the fish region to the TF should be considered, which is now classified as “hyporhithral large.” The species distributions in sites 4 to 7 of River Traun are characteristic to potamal rivers, predominated by species such as *A. bipunctatus, B. barbus, P. phoxinus*, and *S. cephalus*, and low proportions of salmonids (chapters 5.3.1 & 5.3.2). In contrast to salmonid populations, the species mentioned above have relatively natural populations, high recruitment shares, and high reproduction potential (chapter 5.3.3). However, the reference list is based on pristine conditions prior to human impacts with minimal pollution, hydrological and thermal loads. Salmonids cope better with these conditions that correspond to their optimal abiotic habitat. Therefore, the relocation of the fish region is to be seen rather critically and considered carefully.

Future scenarios for major Alpine rivers reaching the year 2049 predict a shift in the species composition by decreasing oligo-stenotherm species and increasing thermophile species (Schmutz et al., 2004). The climate-related brown trout population decrease is already happening, and the self-sustaining ability of native salmonids is questionable in the future (Hari et al., 2006; Schotzko & Jagsch, 2006). The current hyporhithral will change into epipotamal, forcing the climate-induced upstream migration of species adapted to cold water. No stock improvement is observed in the fish stock data of the last ten years, where *S. trutta* and *T. thymallus* average 5 kg/ha or less biomass in River Traun. The reasons are not only due to the temperature but rather caused by factors already described in chapters 5.1 & 6.1. In the upper reaches, salmonid species are limited by the river dimension, ultimately leading to a spatial reduction of the grayling- and brown trout region (Pletterbauer, 2009; Schmutz et al., 2004). Exotic or native, temperature-tolerant species such as rainbow trout or cyprinids may substitute and increase the competition on native species (Geist, 2016; Matulla et al., 2007; Schmutz et al., 2004). Especially *S. cephalus*, *A. bipunctatus,* and partially *B. barbus,* and *P. phoxinus* are the beneficiaries in the rivers Traun and Ager and show a positive trend in density and/or biomass.

Salmonidae dominate the River Alm biomass to a large extent in every period. *T. thymallus* is not found anymore to the same extent as in the 1980s. Due to stocking, *O. mykiss* occurs with higher biomass shares in the last decade, while *S. trutta* shares decrease. Overall, the dominance of salmonids has not been diminished significantly in River Alm; therefore, **hypothesis H2** is rejected.

In River Ager, the cyprinid species have the highest share in biomass with 75 % since 1990, mainly consisting of *S. cephalus* and *B. barbus*. Salmonidae were not dominant within the last 30 years, contributing to the total biomass to maximally 22 % (1990s). Due to the influence of Lake Atter and the thermal load of industrial warm water emitters, the temperature is higher compared to similar water bodies, reaching FRI values between 5.4 and 5.95, indicating cyprinid dominance in the upper reaches of River Ager (Pletterbauer, 2009; chapters 5.1.5 & 6.1). The FRI is likely to increase in the future, leading to a shift in fish species composition in Austrian rivers, as shown using models of various climate scenarios (Schmutz et al., 2004; chapter 5.1.5). However, if considering the reference conditions with the dominant species *A. bipunctatus*, *B. barbus*, *C. nasus*, and *S. cephalus*, it must be assumed that salmonids never dominated in River Ager, which is why **hypothesis H2** is rejected (Petz-Glechner et al., 2007).

The analysis of **fish density and biomass in hydrologically impacted** and unimpacted stretches in Rivers Traun, Alm, and Ager revealed in general higher species numbers, abundance, biomass, and more natural species composition in free-flowing stretches impacted ones. Thus, **hypothesis H7,** "Human alterations of the aquatic habitat are responsible for changes in fish metrics," is validated (Figure 47; Table 10). In fact, 45 % of the sites from Gmunden to Stadl-Paura are impounded, allowing the conclusion that almost half of the river has minimal fish stocks. In contrast, the free-flowing stretches inhabit the great majority of the ichthyofauna. An explanation for the low biomass in the free-flowing section of site Danzermühl may go hand in hand with the renovation of the HPP Danzermühl and the resulting disturbance to fish and habitat in recent years. However, the methodological limitations should be emphasized here, as only riparian habitats were used for the calculation due to the depth conditions of River Traun. The adverse effects of hydropower on fish are subject to various studies, which confirm the gained evidence concerning the altered fish fauna in impoundments (Jungwirth et al., 2003; Kainz & Janisch, 1987; Zauner et al., 2014). The observations by Zauner et al. (2014), where a slightly higher fish stock has been documented in residual flow stretches than in unimpacted stretches of River Traun, are not confirmed overall within the scope of this study (chapters 5.3.4 and 5.3.8).

The way a species abundance value might be misleading is exemplified by *P. phoxinus* in River Alm and *A. mento* in site Steyrermühl: most individuals were caught from one swarm with an estimated catch success rate of 5 % each. The abundance showed the second-highest density for the minnow in river Alm (Table 8) and the highest for *A. mento* in site Steyrermühl (Figure 42). These values are unrepresentative considering the otherwise minor occurrence of the two species in the study area.

6.3.3 Reproduction and population structure

The **population structure of salmonid species** in the investigated rivers is in a poor state overall. Since the investigated stretch of River Traun is in a series of HPPs, and thus large parts are impounded. The available spawning and living habitat is reduced and has possibly become unattractive for rhithral salmonids as a result. However, there are still longer, morphologically intact river stretches, for example, downstream of the HPPs Gmunden and Kemating, which, in theory, are suitable grayling habitats (BMLRT, 2020b). *T. thymallus*, *H. hucho*, and *S. trutta* show a highly disturbed population composition with an underrepresentation of all age classes and a stagnating reproduction potential by missing sufficient adult individuals in every investigated site, which is directly reflected in the relatively low to very low abundance and biomass levels (Figure 43; Table 8). Since little evidence of natural reproduction is provided, it must be assumed that *H. hucho* is not able to maintain a self-sustaining population for several years now (Ratschan & Zauner, 2012). In the case of *S. trutta,* the limited survival probability of juveniles stagnates the natural reproduction ability. The abundance level is mainly dependent on the occurrence of juveniles, whose number represents a significant part of the total species density in healthy populations. However, it is not the case for the reference species *T. thymallus* and *S. trutta* in the investigated rivers (Jungwirth et al., 2003). Downstream of TF and River Ager, the grayling populations look healthier at first sight, but most of the YOY are concentrated in two residual water sections (chapters 5.3.3 & 5.3.8). Thus, at least the self-sustaining ability is secured but is nevertheless on a minimal level, considering the lack of the 0+ age class and the absence of mature individuals outside the residual water areas. The presence of juveniles at these specific locations with altered hydrology suggests that the prevailing habitat conditions with sufficient cover and the possibility of entering the proximate fish pass in case of a potential threat by predators are those favored by juvenile graylings. Here, the hydrological character of the river section with unimpounded and residual water stretches creates heterogeneous habitats populated by different age classes. Also, the comparably high share of *T. thymallus* individuals between 300 and 400 mm contributes significantly to the calculated biomass of 20 kg/ha, which is considered very low for a hyporhithral river.

The operation of HPPs by hydropeaking is suspected to be dangerous for juvenile grayling, as stranding experiments by Horn (2015) and Hasler (in preparation) have shown. Factors such as time of day and lateral bank inclination strongly affect the stranding risk of juvenile grayling under flow fluctuation. At nighttime, the stranding rates were further increased, as did the larvae drift during high flow velocity events. Significant effects of body size have been shown, with smaller fish showing a higher drift risk than slightly larger individuals (Horn, 2015). A discharge analysis downstream of the HPP Gmunden showed that surge/sink phenomena above the critical descent rate for 0+ grayling occurred 15 times in the critical month of May 2015. The stranding risk of > 0.3 - 0.4 cm/min and high-risk events of > 0.5 cm/min occurred a total of five times, whereby a significant impact on larval survival must be assumed (Greimel, personal communication, 2020). Communication and a plan of action with the HPP operators are urgently needed to prevent the abrupt opening and closing of the weirs to guarantee the resilience of juveniles back into the mainstream.

Another factor with a possible negative impact on the genetics of the wild population emanates from **stocking** leading to a reduction in population density and the introduction of non-local genetic lineages. However, it has been so far proved unsuccessful for the Traun grayling. (Uiblein et al., 2000). Therefore, stocking in waters with functioning natural reproduction should be avoided under all circumstances, especially if the stocked fish are of uncertain origin. In the case of the Traun, genetic studies have proven that individuals from Scandinavian and Adriatic catchments were introduced (Pinter, personal communication, 2020). In this case, the consistent and sustainable protection of the existing spawning populations and their needed habitats is a more practical approach (Holzer et al., 2004; Holzer, 2014). In many alpine rivers, stocking became a common management tool and is meanwhile mainly used to increase the attractiveness of waters used for fishing purposes (Jungwirth et al., 2003; von Siemens et al., 2008). Instead of introducing juvenile individuals to balance the recruitment deficit, several tons of exclusively capital *O. mykiss* are introduced in rivers Traun and Alm (Table 3). The additions are reflected in the population structure of salmonids in the investigated rivers by a high proportion of large fish but low reproduction success (chapter

5.3.3). The stocking practices apparently do not enhance the natural reproduction of the introduced species; therefore, the method must be seen critically.

Based on these findings, **hypothesis H3,** “Reproduction and population structure are poor for salmonid species and near-natural for cyprinid species,” must be accepted for Salmonidae in all investigated rivers.

The state of the **population structure of cyprinid species** depends on the river, the sampling site, and the species. *A. bipunctatus* and *P. phoxinus* show healthy population structures with dominant 0+ size classes in River Traun downstream of TF. However, they are absent upstream of TF, where the spirlin is listed as subdominant and the minnow as a dominant species. The remarkably high proportion of juvenile fish in site Lambach increases the species abundance (Figure 46). The demography of *B. barbus* between LT and TF is deficient because all age classes besides large adult individuals are underrepresented. While downstream of TF, the population is comparably well structured with a high proportion of juveniles. *S. cephalus* shows a relatively natural population structure in rivers Traun and Ager in general, except that the 0+ individuals are slightly underrepresented (Traun) or missing (Ager). Higher reproduction rates and habitat variability led to the predominance of the cyprinids *B. barbus* and *S. cephalus* in terms of biomass in rivers Traun and Ager with few exceptions (Kottelat & Freyhof, 2007).

The **hypothesis H3,** “Reproduction and population structure are poor for salmonid species and near-natural for cyprinid species,” must be rejected for the investigated cyprinid species in all rivers, except for *A. bipunctatus*, *S. cephalus*, and downstream TF for *B. barbus* and *P. phoxinus*.

The food selection of the goosander might also alter the reproduction and population of fishes in the Traun catchment. For the already poor stocks of the reference species, this represents another and decisive depletion factor. Due to the preferred prey selection size of approx. 10 to 15 cm, juvenile salmonids and cyprinids are at risk of an additional predator to the cormorant (von Blotzheim, 1992; Weißmeier, 2018). However, difficulties arise to monitor the exact impact of the Goosander on the local stocks, as it releases its excreta differently from the cormorant and thus cannot be detected by the PIT tag method. Only stomach analyses are applicable, but these represent a lethal method for the bird and are therefore not feasible in this case. A study from Bavaria analyzing the stomach content of goosanders concludes that the birds prey on the most abundant and the easiest species to catch (Trauttmansdorff & Rudolph, 2013). In River Traun, these species are not salmonids as the low abundance contradicts these results, but rather cyprinid species (*A. bipunctatus*, *P. phoxinus*, *S. cephalus*). Management measures are particularly difficult to implement as the study area is partly located in bird sanctuaries and the extent of predation on fish stocks is not quantifiable.

6.3.4 Multiple stressors and restoration priorities

Analyzing **multiple stressors** on aquatic systems revealed that hydrologic, morphological, water quality and connectivity stressors affect fish populations through single-acting stressors or the interaction of various stressor combinations (>= 2). Decreasing ecological integrity with increasing stressor magnitude is also observed (Schinegger et al., 2016). Hydromorphological stressors and altered habitats were identified as "significant stress" in a WFD assessment for 48 % and 43% of rivers in Europe, respectively (Aarts et al., 2004); Birk (2019) identifies hydromorphological stress coupled with either nutrient or hydrological stress as the most common types. Fish metrics based on species densities intolerant to water quality degradation and oxygen depletion responded best to single and multiple stressors and their interactions, especially hydrologic and morphological changes (Schinegger et al., 2016; Schmutz et al., 2016). Synergism and antagonism occurred more frequently among stressors than additive interaction. Synergistic effects increase from headwaters to intermediate gradient rivers to large lowland rivers (Schinegger et al., 2016). In response to environmental changes, guilds of highly adapted to local river conditions and threatened key indicator species like *S. trutta* and *T. thymallus*, but also *B. barbus* or *C. gobio*, have declined far more than generalist species in many Alpine rivers (Aarts et al., 2004; Gum et al., 2009; Persat, 1996). In main and secondary channels of floodplains, species suffered most from regulation by declining hydrologic connectivity, areas that typically contain the highest percentage of threatened species (Aarts et al., 2004; Teichert et al., 2016). Rheophilic and limnophilic species have become rare because their lotic reproductive habitats are severely degraded, fragmented, absent, inaccessible, or eutrophic, which applies primarily to juvenile specimens < 150 mm (Aarts et al., 2004, chapter 6.1 & 6.3.1).

The **success of river restoration** measures is dependent on the length of the restored river reach, the time after restoration, and the hydromorphological quality of the measure (Schmutz et al., 2016). While species diversity and density do not respond to restoration, the proportions of small rheophilic species increase, and that of eurytopic decreases. Short- (< 3 years) and long-term effects (> 12 years) of restoration activities have a more decisive influence on fish assemblages than medium-term effects (Schmutz et al., 2016). Future restoration projects should focus on dynamic, self-sustaining, cost-effective habitat improvements extending over several kilometers coupled with river continuity restoration and species reintroduction (Null & Lund, 2012; Schmutz et al., 2016). The restoration of functional fish passes by opening isolated, high-quality, instream or secondary channel fish habitats and riparian areas (e.g., additions of wood, boulders) for the nase and other migratory species in river sections that are inaccessible so far and where reintroduction attempts by stocking alone failed in the last years (Fagan, 2002; Fullerton et al., 2011; Roni et al., 2002; chapter 5.2.8.7 & 5.1.3). The measures are especially applicable in the still free-flowing sections, e.g., downstream of HPP Gmunden, Traunfall, Kemating, and Lambach. Additionally, simultaneous spawning habitat enhancement by sediment introduction to counteract the deepening and colmation of the riverbed in the otherwise sediment-poor River can be realized quickly and can boost fish reproduction, especially for salmonids (Taylor et al., 2019). The development of dynamic, structured sections, e.g., shallow banks by removing the existing structurally poor embankment towards more natural riparian structures, is key for juveniles and small fish species. The gorge section of River Traun consists mainly of one main branch, but downstream of the city of Wels, the restoration of former sidearms according to historical maps must be contemplated where feasible (Figure 4).

The combination of morphological restoration measures with the implementation of ecological flows and mitigation of hydrological stressors due to hydropower production should be envisioned holistically in the future and applied to the Traun catchment to enhance rheophilic species (Schmutz et al., 2015). Furthermore, deadwood shall be left or attached in the river to create turbulent runoff and refuge habitat for fish fry under consideration of hydraulic engineering requirements (von Siemens et al., 2005). According to Teichert et al. (2016), the most significant restoration benefits are expected in mitigating water pollution and oxygen depletion. Chemical water quality has improved significantly in recent decades, but fish fauna recovery is not progressing accordingly in the investigated rivers (chapter 5.1.4).

The increasingly applied barrier removal method is certainly a difficult or impossible undertaking in the River Traun (Brink et al., 2018; O'Hanley et al., 2013). Here, power production is prioritized, and leases typically run for many decades, even though the Kohlwehr (Traun) was demolished recently. Instead, the migration facilitates from the Danube upstream should be continuously rehabilitated gradually to create steppingstone habitats for the recolonization by migratory fish of the Traun and its tributaries. Therefore, to achieve the good ecological state of the investigated rivers in the future, the applications mentioned above are an indispensable prerequisite and must be prioritized.

The risk analysis of the surface water bodies concerning a possible failure to meet the **WFD** objectives for 2027 shows a "definite risk" regarding material loads, including ubiquitous pollutants (general physical-chemical parameters and chemical pollutants), as well as regarding hydromorphological loads (impoundments, residual flow, hydropeaking, migration barriers, morphology), and biological quality elements between HPP Danzermühl and Traunfall, upstream HPP Kemating, and between HPP Stadl-Paura and HPP Lambach (BMLRT, 2021). Although measures are planned to improve the morphological condition in the future, they are limited to the impounded areas. The free-flowing stretches are classified as "good" or "very good" in terms of hydromorphological stress, requiring no action according to the WFD. However, apparent deficits were identified in situ as the lack of natural sediment structures (BMLRT, 2021).

Recreational fisheries must be encouraged to pursue a more ecologically oriented management approach, focusing on natural reproduction of native salmonids, and reducing or eliminating stocking of rainbow trout to a necessary and reasonable extent, especially in stretches with natural brown trout occurrence. Raising awareness among fishers about the importance of ecologically oriented fisheries management and genetic control of hatchery fish is essential here. Until the desired results are achieved, the currently high fishing pressure should be reduced temporarily. A fishery management plan must be developed, including stocking fry and juveniles of species with the genetic origin from the respective catchment.

Importance should also be given to the reintroduction of small fish species from stretches further downstream (Holzer, 2014).

7 Summary

This research provided information on the historical occurrence and abundance of the fish fauna and its temporal change under anthropogenic impacts in the rivers Traun, Alm, and Ager. The method included research of historical sources, assessing the current fish stock, and evaluating quantitative stock surveys of the last 30 to 40 years.

Historical research revealed that the hydromorphological modifications, river engineering measures, the construction of hydropower plants, the deterioration of water quality, and the increase in water temperature had and still harm the fish coenosis today. A distinct influence of stocking large hatchery fish is evident in the population structures of *O. mykiss* and *S. trutta* in rivers Traun and Alm. Furthermore, the predation of *P. carbo sinensis* exerts additional pressure on wild fish stocks, especially on *T. thymallus*, as preliminary results verify the removal of > 30% by the cormorant per winter season.

In River Traun, the comparison of historical information and recent records revealed an increase in species number and total abundance by decade up- and downstream of TF. In contrast, the total biomass decreased from 1980 to 2009 but is increasing ever since. The biomass shares of salmonids dropped from ~55 % (upstr. TF) and 90 % (downstr. TF) in the 1980s to 15 % in the 2010s; the abundance shows similar values. *T. thymallus* is most affected by the reduction and is substituted mainly by *B. barbus* and *S. cephalus* in terms of biomass and *A. bipunctatus* and *P. phoxinus* in terms of abundance.

The fish stock survey in 2019 revealed < 80 kg/ha total biomass in five out of seven sites at River Traun. Between LT and TF, 55 % of the reference species are missing, including *L. lota*. The dominant species *C. gobio, P. phoxinus, S. trutta,* and *T. thymallus* combined account for 11 % of the total catch and < 4 % of the total abundance and biomass. Downstream of TF, 42 % of the reference species are absent, including *C. nasus*; the dominant *T. thymallus* represents < 4 % of the species distribution and total biomass; *B. barbus* has 13% and 18 % share, respectively. The biomass of *T. thymallus* and *S. trutta* is < 5 kg/ha in all sites of River Traun. The occurrence of juvenile grayling is restricted for the most part to residual water stretches of the rivers Traun and Ager. Due to limited reproductive success, habitat deficits, and human impacts, autochthonous salmonids are in poor overall condition in the investigated rivers and are gradually substituted by cyprinid species.

In River Alm, the abundance has been relatively constant over four decades, while the biomass has been mostly below 45 kg/ha since 2000. The analysis of quantitative stock surveys indicates a significant decline of grayling (> 60% biomass in the 1980s) and brown trout (> 75% in the 2000s) to less than 10%, respectively 40% in the current survey. The species composition is characterized by the absence of almost all subdominant and rare reference species, mainly caused by river continuum interruptions. The natural reproduction of brown- and rainbow trout functions for the most part, but not of grayling. Overall, the total biomass is significantly low at 35 kg/ha.

In River Ager, the biomass (Ø > 130 kg/ha in the last 20 years) and abundance are generally higher since 1990 than the other rivers and mainly dominated by cyprinids *B. barbus* and *S. cephalus*. The actual fish stock surveys confirmed the findings, but the 0+ and partly the 1+ generations are largely missing. Salmonids have minor shares in the total abundance of ~1,500 Ind/ha and total biomass of 169 kg/ha distribution in River Ager.

The adverse effects are likely to intensify over the following years, as a climate-induced shift in fish species community from grayling- to barbel region is expected. To sustainably improve the condition of the fish fauna, steps must be taken soon to enhance the habitat, improve spawning grounds for lithophilic species, reintroduce and establish reference species, eliminate the conflict between fisheries and bird conservation, reduce the predation pressure of the cormorant, and adopt an ecologically oriented fisheries management approach. Future research should ensure the success of the measures through appropriate monitoring programs.

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9 Appendix

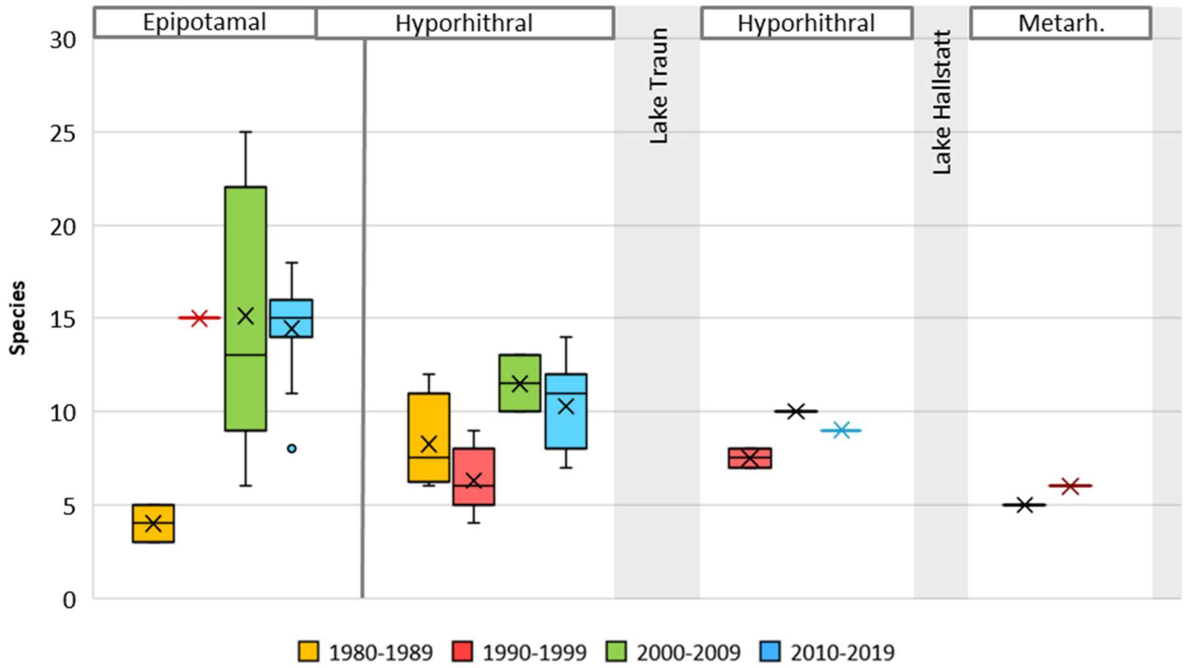

Figure 53: Species number boxplot of fish stock assessments in the longitudinal course of the River Traun; separated by fish regions and decades.

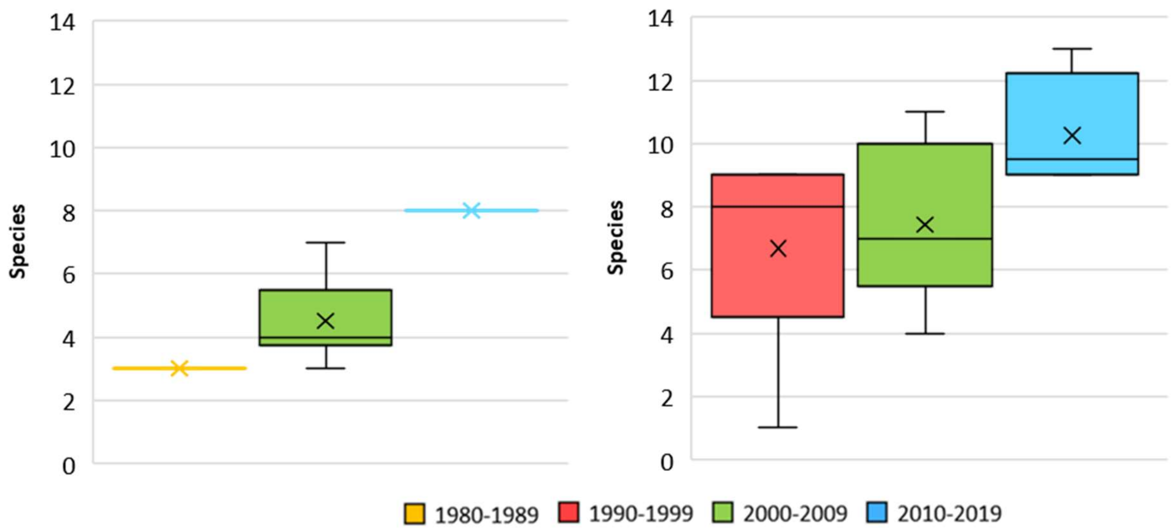

Figure 54: Species number boxplots of fish stock assessments in the longitudinal and temporal course of the River Alm (left) and River Ager (right); separated by decades.

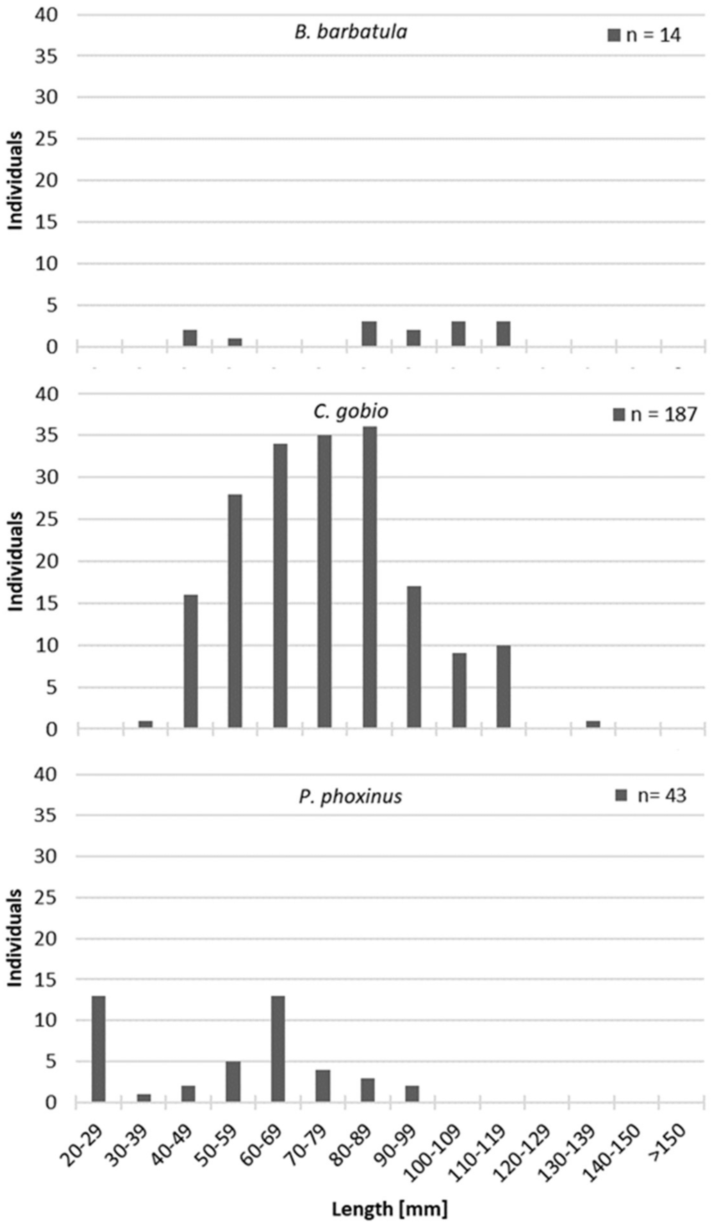

Figure 55: Population structure B. barbatula, C. gobio, and P. phoxinus in River Alm.

Table 11: Mesohabitat selection in kg/ha biomass of the River Traun (species with total biomass of > 10 kg/ha and total catch number of n > 10 displayed).

Species	Inner bank	Inner bank shifted	Mid-stream	Outer bank shifted	Outer bank	Bank	Bank/ branch	**Total**
A. bipunctatus	5	<1	2	<1	11	21	<1	40
B. barbus	4	33	101	8	11	12	-	169
E. lucius	1	4	2	6	3	2	2	21
O. mykiss	3	7	14	10	11	1	-	46
S. trutta	2	<1	4	3	3	1	-	12
S. cephalus	46	8	24	8	78	54	24	241
T. thymallus	<1	2	14	4	1	<1	-	20
Total	61	53	159	39	119	92	26	549

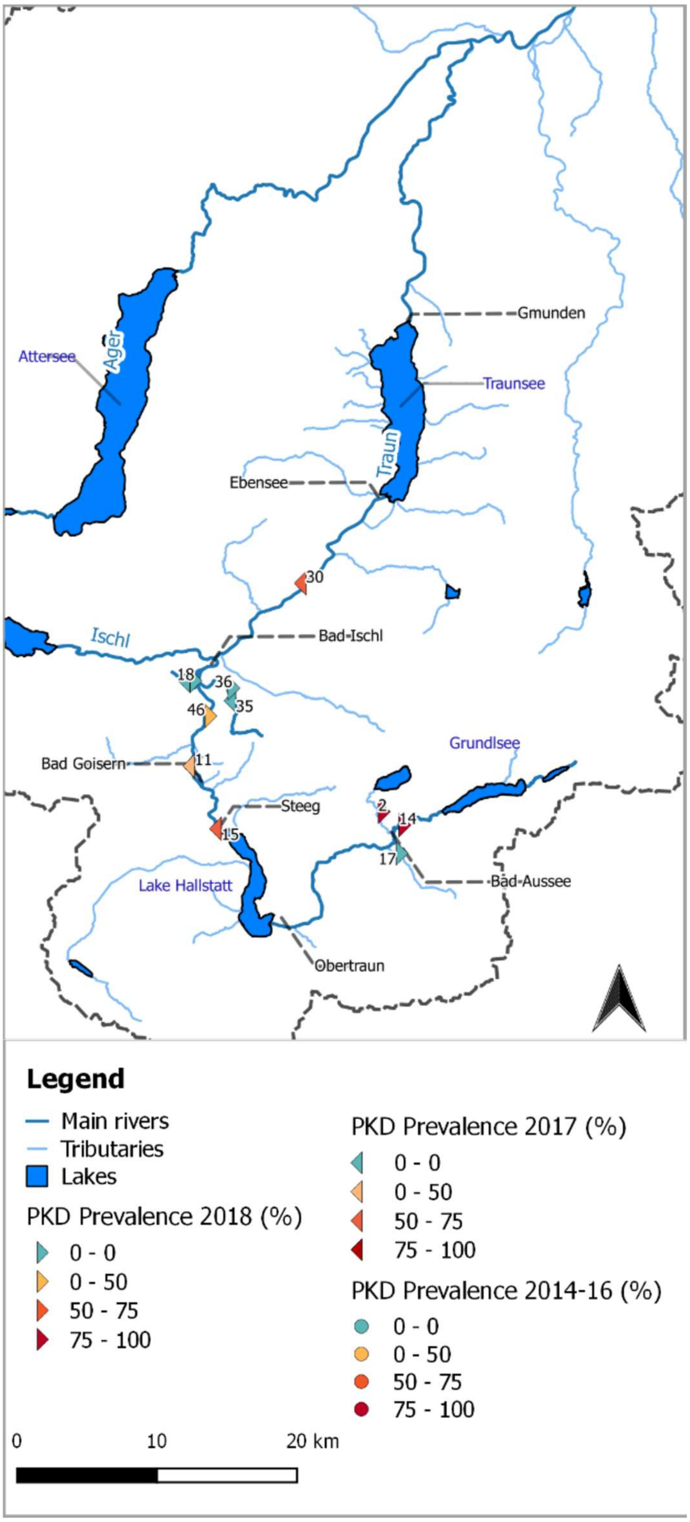

Figure 56: Analysis results on PKD prevalence in River Traun and its tributaries from 2014 to 2018; based on data collected for the Climate Trout project (Borgwardt et al., 2020; Borgwardt, personal communication, 5 November 2020).

Table 12: Fish species listed as "Other" in Figures 21 & 23.

Abundance Traun	Biomass Traun	Biomass Ager	Biomass Alm
Abramis brama	*Abramis brama*	*Alburnoides bipunctatus*	*Barbatula barbatula*
Alburnus alburnus	*Alburnoides bipunctatus*	*Alburnus alburnus*	*Gobio gobio*
Alburnus mento	*Alburnus alburnus*	*Alburnus mento*	*Leuciscus leuciscus*
Anguilla anguilla	*Alburnus mento*	*Anguilla anguilla*	*Oncorhynchus mykiss*
Barbatula barbatula	*Anguilla anguilla*	*Barbatula barbatula*	*Phoxinus phoxinus*
Carassius carassius	*Barbatula barbatula*	*Carrassius gibelio*	*Rutilus rutilus*
Carrassius auratus	*Carassius carassius*	*Chondrostoma nasus*	*Squalius cephalus*
Carrassius gibelio	*Carrassius auratus*	*Cottus gobio*	
Chondrostoma nasus	*Carrassius gibelio*	*Cottus gobio*	
Cobitis taenia	*Chondrostoma nasus*	*Esox lucius*	
Cottus gobio	*Cobitis taenia*	*Gobio gobio*	
Cyprinus carpio	*Cottus gobio*	*Hucho hucho*	
Esox lucius	*Cyprinus carpio*	*Leuciscus leuciscus*	
Gasterosteus aculeatus	*Gasterosteus aculeatus*	*Oncorhynchus mykiss*	
Gobio gobio	*Gobio gobio*	*Perca fluviatilis*	
Gymnocephalus cernua	*Gymnocephalus cernua*	*Phoxinus phoxinus*	
Hucho hucho	*Hucho hucho*	*Proterorhinus seminularis*	
Leuciscus leuciscus	*Leuciscus leuciscus*	*Rutilus meidingeri*	
Lota lota	*Neogobius melanostomus*	*Rutilus rutilus*	
Neogobius melanostomus	*Phoxinus phoxinus*	*Salmo trutta*	
Proterorhinus seminularis	*Proterorhinus seminularis*	*Silurus glanis*	
Pseudorasbora parva	*Pseudorasbora parva*	*Tinca tinca*	
Rutilus meidingeri	*Rutilus meidingeri*		
Rutilus rutilus	*Rutilus rutilus*		
Salmo trutta lacustris	*Salmo trutta lacustris*		
Salvelinus fontinalis	*Salvelinus fontinalis*		
Salvelinus umbla	*Salvelinus umbla*		
Sander lucioperca	*Sander lucioperca*		
Scardinius erythrophthalmus	*Scardinius erythrophthalmus*		
Silurus glanis	*Silurus glanis*		
Squalius cephalus x Alburnus mento	*Squalius cephalus x Alburnus mento*		
Telestes souffia	*Telestes souffia*		
Tinca tinca	*Tinca tinca*		
Vimba vimba	*Vimba vimba*		

Table 13: Catch numbers (n), share (%), Ø length (mm) and Ø weight (g); divided by reference stretch upstream of TF (ID 1 - 3), downstream of TF (ID 4 - 7), and total (ID 1 -7).

	Traun ID 1 to 3					Traun ID 4 to 7					Traun total ID 1 to 7			
Species	**Reference[1]**	**n [-]**	**share [%]**	**Ø length [mm]**	**Ø weight [g]**	**Reference[2]**	**n [-]**	**share [%]**	**Ø length [mm]**	**Ø weight [g]**	**n [-]**	**share [%]**	**Ø length [mm]**	**Ø weight [g]**
A. brama	r					s								
A. ruthenus						r								
A. bipunctatus	s					r	1128	42	75	6	1128	32	75	6
A. alburnus		4	1	43	1	s					4	<1	43	1
A. mento	s	54	7	68	6	r	10	<1	69	4	64	2	68	5
B. barbatula	s					s	31	1	88	4	31	1	88	4
B. barbus	s	129	17	259	458	d	345	13	155	160	474	14	184	241
C. carassius						r								
C. nasus						d								
C. elongatoides						r								
Coregonus sp.	r													
C. gobio	d	30	4	67	7	s	60	2	73	9	90	3	71	8
E. lucius	s	6	1	673	3182	s	34	1	381	825	40	1	424	1179
E. mariae	r					r								
G. gobio	s					s	37	1	108	19	37	1	108	19
G. cernua						r								
H. hucho		4	1	850	6786	s	4	<1	786	7815	8	<1	818	7301
L. idus						s								
L. leuciscus	s					s	6	<1	152	40	6	<1	152	40
L. lota	d					s								
M. fossilis						r								
O. mykiss		86	11	371	622		28	1	332	480	114	3	362	587
P. fluviatilis	s	78	10	182	29	s	41	2	156	24	119	3	173	27
P. phoxinus	d	1	<1	30	<1	s	319	12	61	3	320	9	61	3
P. semilunaris		4	1	48	3		46	2	45	3	50	1	45	3
P. parva							1	<1	80	4	1	<1	80	4
R. amarus						r								
R. meidingeri	r					r	3	<1	135	31	3	<1	135	31
R. pigus						r								
R. rutilus	r	34	4	122	16	s	3	<1	162	46	37	1	125	19
S. trutta	d	31	4	232	173	s	43	2	250	213	74	2	243	196
S. trutta lacustris	s					r								
S. lucioperca						r								
S. erythrophthalmus						r								
S. glanis						r								
S. cephalus	s	288	37	182	188	s	489	18	199	262	777	22	193	235
Sq. ce. x Al. me.		1	<1	220	128						1	<1	220	128
T. souffia						r								
T. thymallus	d	22	3	287	287	d	86	3	220	170	108	3	233	194
T. tinca	r					r								
V. vimba	r					r								
Z. streber						r								
Z. zingel						r								
Total	22	772	100	212	295	39	2714	100	122	107	3486	100	75	6

Table 14: Biomass and abundance of all species at River Traun.

Species		**Gmunden**		**Danzermühl**		**Steyrermühl**		**Traunfall**		**Kemating**		**Stadl-Paura**		**Lambach**		**Total**	
Biom.	**Abun.**	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha	kg/ha	Ind/ha
A. bipunctatus								3	750	13	2210	1	162	22	2863	40	5986
A. alburnus		0	6			0	5									0	11
A. mento		0	123	1	46	0	385	0	7	0	24	0	1			2	586
B. barbatula								0	4	0	67	0	5	0	123	1	198
B. barbus		51	57	3	40	58	119	11	78	16	343	8	58	21	1327	169	2021
C. gobio		0	25	0	5	0	2	0	39	0	57	0	12	1	61	2	200
E. lucius		1	0	3	1	1	5	10	10			3	7	2	3	20	27
G. gobio												1	30	3	115	3	146
H. hucho		11	2					16	1	1	0	1	1			29	4
L. leuciscus										0	1	0	5			0	6
O. mykiss		28	49	5	6	3	2	2	8	1	2	4	7	3	23	46	98
P. fluviatilis		2	78	0	7	1	50	0	14	0	2	1	30	1	15	5	197
P. phoxinus		0	1					0	68	1	249	0	86	4	1483	5	1887
P. marmoratus						0	9	0	16	0	57	0	24	1	144	1	251
P. parva														0	17	0	17
R. meidingeri												0	3			0	3
R. rutilus		3	155					0	4			0	4			3	162
S. trutta		2	16	0	1	1	2	1	11	3	23	1	2	5	33	13	88
S. cephalus		64	566	18	227	12	42	11	93	13	376	115	482	8	344	241	2132
S. cephalus x A. mento		1	5													1	5
T. thymallus		4	10	2	11	2	7	4	11	2	4	4	66	3	24	21	133
Total		**169**	**1093**	**33**	**345**	**78**	**628**	**60**	**1114**	**50**	**3414**	**139**	**985**	**73**	**6576**	**602**	**14155**

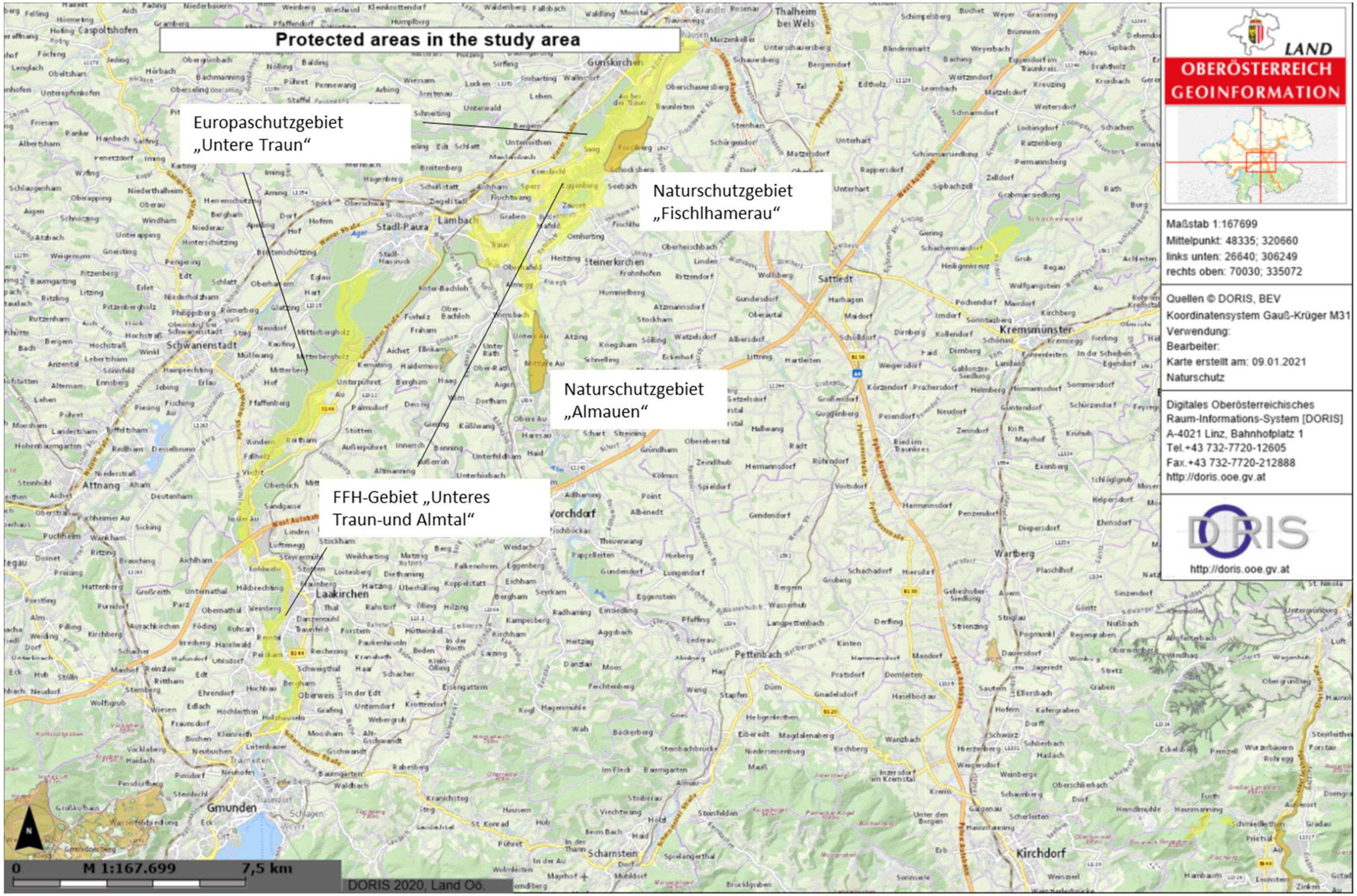

Figure 57: European and national protected areas in the investigation area (DORIS, 2021).

Table 15: Biomass, abundance, and location of past fish stock surveys of rivers Traun, Alm, and Ager.

Year and site	Ø River-km	Biomass total [kg/ha]	Abundance total [Ind/ha]
Traun			
1985			
Traun Rückstau Welser Wehr	37,35	121,2	145,8
Traun uh Almmündung	41,65	282,1	329,1
Traun uh Danzermühl	64,7	80,8	122,4
Traun uh Gschröff	61,6	18,1	17
Traun uh Kohlwehr	63,7	116,2	127,1
Traun uh Rheintalmühle	65,6	28,3	37,8
1992			
Traun Stau KW Siebenbrunn	61,2	14,7	157,1
Traun Stauwurzel KW Siebenbrunn	61,7	110,7	401,2
Traun Steyrermühl	62,5	12,2	37
Traun upstream KW Steyrermühl	63,4	49,6	134,7
1994			
Traun Bad Ischl	104,5	240,5	807,4
1995			
Traun Bad Ischl	103,81	742	1505,9
1996			
Traun Steeg	116,8	44,8	101,6
Traun Steegwirt	118,1	242,7	447,9
1998			
Traun uh KW Marchtrenk	24,1	158,2	1136,2
1999			
Traun Bad Aussee	141	170,2	850,5
Traun Seeausrinn Grundlsee	145,2	41,8	580,8
2000			
Stauwurzel/Traunspitz bei Lambach	49	5	12,4
Traunstau Lambach	46,8	8,4	34,5
2001			
Traun Umgehungsgerinne KW Lambach HITIAG		231	3031
Traun Umgehungsgerinne KW Lambach linksufrig (Lambach)		112	7065
Traun Umgehungsgerinne KW Lambach linksufrig (Schwaigbach)		344	5996
Traun Umgehungsgerinne KW Lambach rechtsufrig (Paura)		129	7215
2003			
Traun Umgehungsgerinne KW Lambach linksufrig (Lambach)		293	8648
Traun/100 m oh Brücke bei Haltestelle Koppenbrüllerhöhle	130,7	91,4	1371,7
2005			
Stauwurzel/Traunspitz bei Lambach	48,95	61,2	693,7
2008			
Traun Ebelsberg	6,05	330,4	5627,3
Traun1 Plankau	88,1	18,3	220,6

Traun2 Gmunden	72,05	38,9	295,3
Traun3 Marchtrenk	23,85	59,5	2151,8
Traun4 Pucking	15,85	11,4	471,7
2009			
Traun Ebelsberg	6,06	277,7	2756,3
Traun Umgehungsgerinne KW Lambach oben	45,1	104	1917
Traun Umgehungsgerinne KW Lambach unten	45	34	2944
Traun1 Plankau	88,11	24,1	214,3
Traun2 Gmunden	72,06	14,4	217
Traun3 Marchtrenk	23,86	61,8	3172
Traun4 Pucking	15,86	4	48,3
2012			
Traun Ebelsberg	6,2	311,4	15628,4
2014			
Traun Ebelsberg	6,75	207,6	27337,4
Traun Stadl-Paura Unterwasser	47	204,8	5648
Unterwasser KW Pucking	12,6	37,2	6455,3
2016			
Gmunden uh. Kraftwerk	69	108,6	593,6
Traun Restwasser KW Traunfall	58,3	112,4	1521
2017			
Traun Ebensee	92,5	13	64
Traun uh KW Gmunden	70,7	246,8	503,4
2018			
Traun Stadl-Paura Unterwasser	47,01	240,2	5532,8
Traun Steyrermühl	62,6	27,2	51,4
Traun uh KW Kemating	53	18,4	376,4
Traun uh Wehr Gschröff	60,65	9,8	28,7
2019			
1 Gmunden	68,5	169,0	1092,7
2 Danzermühl	64,1	32,0	342,5
3 Steyrermühl	61,15	77,5	628,3
4 Traunfall	56,55	59,9	1112,0
5 Kemating	51,85	49,8	3414,2
6 Stadl-Paura	48	139,2	984,8
7 Lambach	44,15	73,1	6520,4
Traun uh Danzermühl	64	118,5	686,4
Alm			
1985			
Alm oh Mündung	0,55	67,3	525
Alm uh Wimsbacher Brücke	2,55	56,8	892
2007			
Alm1 Lippenannerl	32,5	14,5	246,8
Alm2 Lederau	19,5	34,8	349,3
2008			
Alm1 Lippenannerl	32,51	15,7	717,9
Alm2 Lederau	19,51	76,5	1592,2
Alm3 Almspitz	0,8	8,5	737,5

2009			
Alm3 Almspitz	0,81	9,8	1438,1
2019			
Alm	4,95	35,1	744,0
Ager			
1990			
Dürnau	26	5,1	42
Lenzing	31	16,4	284
Puchheim	17,5	128,4	380
1993			
Dürnau	26,6	2	349
Lenzing	31,01	44,5	508
Puchheim	17,51	47,9	247
Staig	6,5	47,1	775
1994			
Deutenham	12,5	556,3	5606
Dürnau	26,61	81,8	794
Fischerau	1,2	39,1	665
Lenzing	31,02	28,1	359
Puchheim	17,52	107,2	672
Staig	6,51	141,8	3450
2008			
Ager Fischerau	1,5	28,7	825,3
Ager1 Dürnau	24,6	525,3	5733,8
Ager2 Oberlixlau	23,1	199,7	14429,6
Ager3 Deutenham	13,3	183,7	705,1
Ager4 Aham	13,32	439,8	5670,7
2009			
Ager1 Dürnau	24,61	263,8	2484,3
Ager2 Oberlixlau	23,11	304,5	2227,2
Ager3 Deutenham	13,31	47,2	215,5
Ager4 Aham	13,33	108,6	1164,2
2010			
Ager Fischerau	1,51	30,3	576,4
2014			
Ager Fischerau	1,52	155,9	2302,7
2018			
Ager4 Aham	13,34	188,2	3286,7
2019			
Ager 1	1,7	168,830507	1555,67502

Table 16: Catch figures of the five most frequently caught species by P. carbo sinensis in the River Traun; subdivided by the hydromorphological impact.

	Impact			
Species	None	Impoundment	Residual water	**Total**
E. lucius	8	20	12	40
O. mykiss	103	11		114
P. fluviatilis	91	8	20	119
S. cephalus	481	253	43	777
T. thymallus	69	2	37	108