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Historical fish market data and fish ecological changes in the Austrian Danube

from 1860 to 1914

Master thesis

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submitted by:

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Vienna, 2015

Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Christina Gruber Vienna, 02/04/2015

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Abstract

The present thesis aims to reconstruct the fish community changes of the Austrian Danube from 1865 to 1914. As fish ecological investigations started mostly in the late 20th century, other data sources needed to be considered to gain insights into past fish ecological conditions. For this thesis data from the Viennese fish market were used to test whether fish trading information reflects the ecological conditions of regional waters. The market data provided information about Danube fish species and the amounts traded. The identification of fish species originating from the Austrian Danube was done by reviewing contemporary literature and by comparing them with legal regulations, i.e. closed seasons. Subsequently, the amounts of fish species delivered to the market and habitat changes during the studied period were examined. The spatial analysis in ArcGIS provided information about the hydraulic structures installed in the river, covering the period of the systematic river channelization. The results showed that the aquatic habitat composition changed drastically due to the hydraulic structures, especially closure dams decoupled the floodplains from the main channel. In a next step the annual deliveries of Danube fish delivered to the market – in kg/year – were compared with the annual length of hydraulic structures installed in the Austrian Danube. The combined analysis showed that changes in the fish composition at the market were to a large part (about 50 %) owed to hydraulic structures in the Austrian Danube. Considering the multitude of factors influencing the fish market data, this result was significantly high. This thesis may contribute to the reconstruction of the past fish community along the Danube and its former hydraulic structures for a period that represented a more dynamic state than at present. The study also may provide important data for future restoration measures.

Kurzzusammenfassung

Die vorliegende Arbeit rekonstruiert Änderungen in der Fischgemeinschaft der österreichischen Donau von 1865 bis 1914. Da fischökologische Untersuchungen vorwiegend erst im späten 20. Jahrhundert begannen, mussten andere Datenquellen herbeigezogen werden, um Einblicke in den fischökologischen Zustand zu gewinnen. Verwendet wurden Daten vom Wiener Fischmarkt. Es wurde untersucht, ob ein Zusammenhang zwischen diesen Informationen und dem tatsächlichen Fischbestand in der Donau belegt werden kann. Die Marktdaten umfassten Angaben über einzelne Fischarten und deren jährliche, teils monatliche oder wöchentliche Liefermengen. Die Identifizierung von Donaufischarten wurde mittels zeitgenössischer Literatur und dem Vergleich mit gesetzlichen Bestimmungen, z. B. den Schonzeiten, durchgeführt. Anschließend wurden die Liefermengen an Donaufischen und die Habitatveränderungen während des untersuchten Zeitraums ermittelt. Die räumliche Analyse in ArcGIS lieferte detaillierte Informationen über die Regulierungsbauwerke im Fluss. Die Ergebnisse zeigten, dass sich die Zusammensetzung der aquatischen Lebensräume, aufgrund der hydraulischen Bauwerke, drastisch verändert hat. Gravierende Eingriffe bestanden in der Errichtung von Dämmen an Seitenarmen, die zur Entkoppelung der Neben- und Augewässer führten. In einem nächsten Schritt wurden die jährlichen Lieferungen von Donaufischen an den Markt - in kg / Jahr - mit der Länge an jährlich installierten Wasserbauwerken in der österreichischen Donau verglichen. Die kombinierte Analyse zeigte, dass die Änderungen der Fischzusammensetzung auf dem Markt zu einem großen Teil (ca. 50%) auf die Errichtung von Wasserbauwerken in der österreichischen Donau zurückzuführen sind. Angesichts der Vielzahl an Einflussfaktoren auf die Fischmarktdaten war das Ergebnis signifikant hoch.

Die Ergebnisse dieser Arbeit sind eine Grundlage für die Beschreibung der historischen Fischgemeinschaft und der Wasserbauwerke in dem untersuchten Zeitraum entlang der Donau. Die Studie kann auch wichtige Daten für künftige Renaturierungsmaßnahmen liefern.

Contents

1 Introduction

Humans use rivers and their surrounding landscapes more than any other type of ecosystem in the whole world. As a result, most of the large river systems have lost their original functional integrity (Tockner & Stanford, 2002). In the last two decades reference conditions to elaborate possible restoration and conservation measures have often been based on an assumed unimpaired status and as such, pre-industrial conditions have served as a baseline.

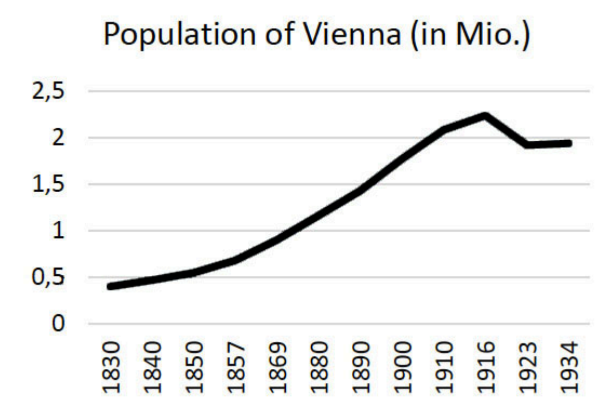
The present thesis aims at reconstructing the past fish community of the Austrian Danube from the late 19th to the beginning of the 20th century. Thus, a preindustrial state in a strict sense is not covered by the studied period. Nevertheless the conditions prevailing at that time can provide insights into a more dynamic state of a river and it can act as adequate substitutes for historical reference conditions (Swetnam et al., 1999; Stoddard et al., 2006). In the European Union the most important legislations for rivers are the Water Framework Directive (WFD, Directive 2000/60/EC) and the Flora, Fauna, Habitat Directive (FFH, Directive 92/43/EEC). The Water Framework Directive refers to the "natural conditions" of rivers, lakes and estuaries with no or only less human modifications (Directive 2000/60/EC). Historical surveys can be an approach to detect their "natural conditions". It has to be noted, however, that historical reference conditions of a river often cannot be fully restored, as recently remarked by some scientists (Dufour, 2009; Szabo & Hedl, 2011). This can be for instance because of altered hydrology due to climate change, modified sediment transport due to being trapped behind dams or because of introduced species which have become established.

Investigating the historical conditions of ecosystems implies several methodological difficulties. Due to a lack of sufficient and comprehensible data about the presence of fish species and their abundances in pre-industrial times most existing studies consider sources from the 19th century (Haidvogl et al., 2014). For the Austrian Danube fish ecological surveys only exist since the last decades of the 20th century (Horne & Goldman, 1994). Inevitably other sources need to be considered. Haidvogl et al. (2014) propose a classification scheme of printed and archival sources and describe their fish ecological information. They identified five types of sources: (i) early scientific surveys, (ii) fishery sources, (iii) fish trading sources,

(iv) fish consumption sources and (v) cultural representations of fish. Besides the early scientific surveys, the sources were produced within various economic and administrative contexts and do thus not provide direct information about the fish assemblages of specific rivers. Current research by Haidvogl & Pont (2013) showed the suitability of fish trading sources, i.e. fish market registers, which hold information about fish species and the amounts traded at the market, for reconstructing the fish composition of the Austrian Danube. This thesis will further explore and prove the potential of Viennese fish market data to reflect the situation in the local and regional aquatic systems, i.e. the Danube. Specifically, the changes in the fish assemblage at the Viennese fish market are compared with hydromorphological alterations (hydraulic structures installed along the river). Since the latter could have modified practices of fisheries in the Austrian Danube, commercial fishing was studied too.

The Viennese fish market data cover the period from 1867 to 1914. During this time industrialization took place with major impacts on the environment. One of the biggest changes for the Austrian Danube was the systematic river channelization which was mainly motivated by problems with navigation because the passage of the Upper Danube was full of obstacles, dangers and the navigation line was constantly changing. The introduction of steam ship traffic in the Austrian Danube in the 1830s increased the need for a hazard-free passage. Flood protection was a second reason for river training works, but it was accomplished in the 19th century only in large urban centres such as Vienna. Furthermore, the engineering works were only possible due to the technological developments of that time. Throughout the whole Austrian Danube the riverbanks were reinforced and one single river channel was built. As a result the fish assemblage was influenced profoundly (Schiemer & Waidbacher, 1992). Apart from the alterations of fish habitats, commercial fishery also had a severe impact on the fish assemblage. Overexploitation and the disregard of closed seasons changed the fish composition. As indicated above, there might be also a link between the river channelization and commercial fishery because closure dams and guiding walls might have prevented the access of boats to floodplain water bodies.

Vienna, the capital of the Austro-Hungarian Monarchy forms the basis for the analysis. The town is a well-documented example for the changes that took place during the studied period in the whole Austrian Danube. In addition, the fish data stem from the Viennese fish market, which further justify Vienna as the main point of observation.



Population of Vienna (in Mio.)
2,5
2
1,5
1
0,5
0
1830
1840
1850
1857
1869
1880
1890
1900
1910
1916
1923
1934

1.1 Research Questions and Hypotheses

This thesis focuses on the reconstruction of the fish composition in the Austrian Danube from 1860 to 1914 based on data from the Viennese fish market. It investigates aquatic habitat changes (due to river regulation) and changes in fishing practices as the main possible drivers of the fish composition changes found on and reported for the market. Historical maps and contemporary literature will be used to describe these drivers.

The main study focus of this thesis is split into three research questions which aim to identify and explain links between the fish community changes as observed from the fish market data and the alterations of habitats and fishing practices in the Danube:

- Is there a relation between historical statistics of the Viennese fish market and the actual fish community of the Danube?
- Did the Danube regulation (systematic river channelization) impact the aquatic habitats and if so did the habitat change have an impact on the fish composition?
- Did the hydraulic structures along the Danube influence the commercial fishing practices in the Danube by preventing direct access to disconnected side arms or floodplain water bodies?

These research questions lead to the following hypotheses that will be investigated and discussed in this thesis.

- There is a relation between the fish composition on the Viennese fish market and the actual fish composition of the Austrian Danube and this relation can be proved by reconstructing the habitat conditions and its changes.
- The Danube regulation changed the aquatic habitats composition and these changes had a negative impact on the fish community of the Austrian Danube.
- The commercial fishing practices in the Austrian Danube were influenced by the hydraulic structures along the Austrian Danube.

2 Study Site

2.1 The Austrian Danube

The Austrian Danube is part of the Upper Danube. It stretches from the Austrian border with Germany in Passau, where the Inn flows into the Danube, to the inflow of the March at "Theben" (Devin) at the border with Slovakia. With about 350 km about 12.5 % of the total river (total length about 2800 km) flows on Austrian territory (Fig. 3). The Danube as it is in Austria an alpine river and characterized by comparably high slope and flow velocity (OÖ Statthalterei, 1909). The average slope is 0.045% and the mean annual discharge in Vienna amounts to 1950 m^3s^{-1}.

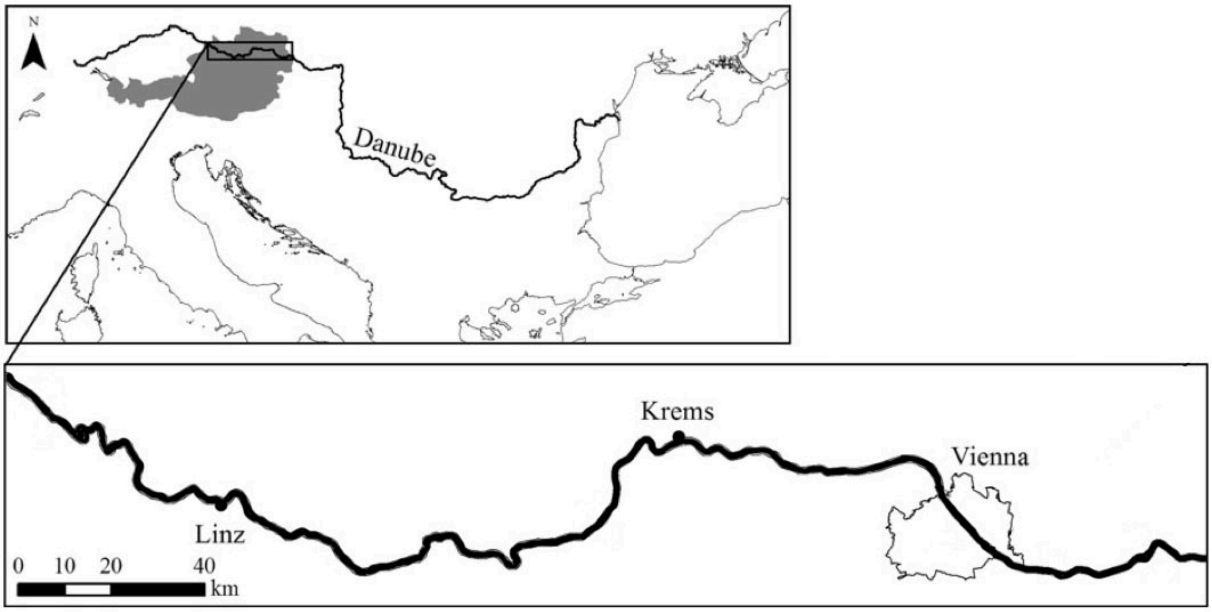
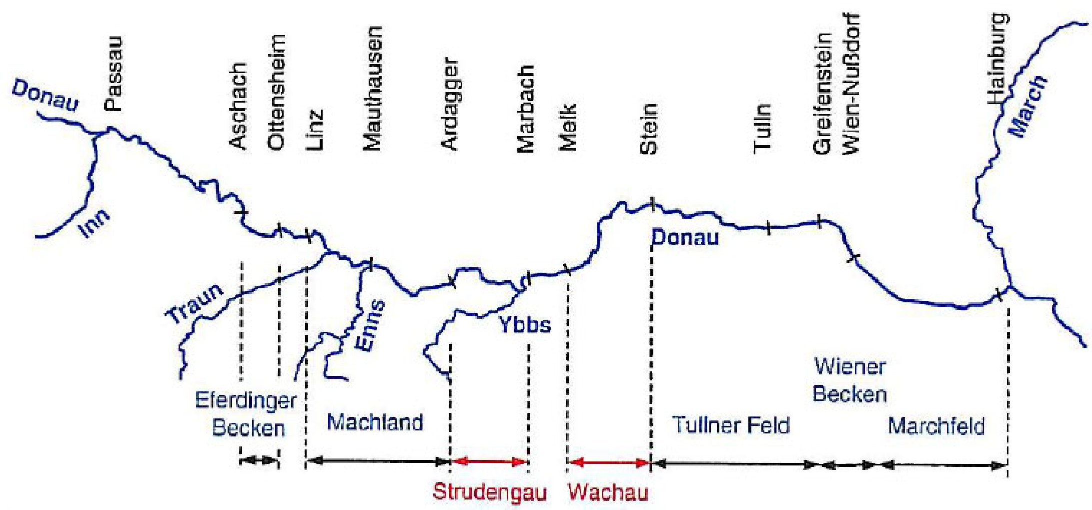


Figure 3: Study site with major cities in Austria and its position within the Danube in the upper part (author/Schmutz et al., 2013).

2.1.1 Breakthrough stretches and anabranching stretches of the Danube in Austria

Two different types of landscapes shape the Austrian Danube. On the one hand steep, narrow breakthrough stretches through mountainous areas and on the other hand vast anabranching stretches characterize the river. In the anabranching stretches the Danube flows in its own alluvium (self-deposited sediments) and without e.g. geological obstacles the river reaches wide extensions (ICPDR, 2005). One finds high habitat turnover rates, floods and erosion processes that continuously alter the river course and form gravel banks and islands. The aquatic habitats follow specific successions and one finds typical shifts from



Donau
Passau
Inn
Aschach
Ottensheim
Linz
Mauthausen
Ardagger
Marbach
Melk
Stein
Tulln
Greifenstein
Wien-Nußdorf
Hainburg
March
Traun
Enns
Ybbs
Donau
Eferdinger Becken
Machland
Strudengau
Wachau
Tullner Feld
Wiener Becken
Marchfeld

Melk - Stein (Wachau)	2035-2002 (33 km)
Nußdorf-Greifenstein (Wiener Pforte)	1949-1932 (17 km)

Anabranching stretches:

Eferdinger Becken (Aschach – Ottensheim)	2160-2144 (16 km)
Machland (Linz-Ardagger)	2135-2085 (50 km)
Pöchlarn	2049-2035 (14 km)
Tullnerfeld (Krems Stein – Wien)	2002-1949 (53 km)
Wiener Becken & Marchfeld (Wien – Marchmündung)	1932 – 1892 (47 km)

This thesis focuses on the basin stretches of the Austrian Danube, as most of the systematic river channelization (due to hydraulic structures) took place there. According to research from Schmautz et al. (2000) the basin stretch between Marbach and Melk (river km 2049-2035) and the breakthrough stretch between Greifenstein and Nußdorf (river km 1949-1932) were left out, because they were ultimately too small for the investigation of anthropogenic impacts based on the sources used here.

2.2 Fish Fauna of the Austrian Danube

A large number of species and the ecological diversity of the community characterize the fish fauna of the Austrian Danube (Jungwirth, 1984; Schiemer & Spindler, 1989; Jungwirth et al., 2014). Following the fish region typology of Thienemann (1925) the Austrian Danube belongs to the barbel zone, which is equivalent to the epipotamal (Huet, 1949) and mainly dominated by cyprinids, namely by the barbel.

The present list of reference fish species ("Referenzfischzönosen" in Schotzko & Wiesner, 2007 after Haunschmid et al., 2006, Table 2) takes into account for the Austrian Danube three different sections. These are based on two ecoregions (Eastern Alpine foothills and Lower Alpine foothills) and the geomorphological type (anabranching and breakthrough sections) (Table 1).

Haunschmid et al. (2006) describe the species present in the three sections of the Austrian Danube and their relative abundance in the three classes: dominant (Leitart), subdominant (Begleitart) and rare species (seltene Begleitart). Basically, dominant species appear in high abundances. Predators, such as the Danube salmon, will, however, be always less abundant than species on lower trophic levels, such as nase (*Chondrostoma nasus*) and bleak (*Alburnus alburnus*). Often predators, in particular, are sensitive to altered habitat situations and they are for that reason good indicators of ecological changes in the river (Zauner & Eberstaller, 1999). Subdominant species mostly appear in relatively moderate abundances. Rare species have relatively low frequencies (Haunschmid et al., 2006).

Schotzko & Wiesner (2007) mention barbel (*Barbus barbus*), bream (*Abramis brama*), bleak, nase, ide (*Leuciscus idus*), Danube salmon (*Hucho hucho*) and dace (*Leuciscus leuciscus*) as dominant and characteristic of the Austrian Danube.

The present list of fish in the Austrian Danube still reflects the historical situation to a large extent (Heckel & Kner, 1858; Siebold, 1863), all apart from the disappearance of the big sturgeon species (Acipenseridae). These seasonal migrants (beluga sturgeon (*Huso huso)*, stellate sturgeon (*Acipenser stellatus)*, Russian sturgeon (*Acipenser gueldenstädtii)* and ship sturgeon (*Acipenser nudiventris))* from the Black Sea were already very rare on the Viennese fish market in the second half of the 19th century and the beginning of the 20th century (Krisch, 1900), due to overfishing, but some specimen could still be found (Schiemer & Waidbacher, 1992). Already in the 19th century only one sturgeon species, the sterlet (*Acipenser ruthenus*) as pure freshwater species could have still been found in considerable numbers (Heckel & Kner, 1857). The beluga, Russian, ship and stellate sturgeon were abundant in the Austrian waters in the Middle Ages, but due to overfishing in the Upper and Middle Danube they have became very rare by the beginning of the 19th century and migrated mostly only up to Bratislava (Fitzinger & Heckel, 1836; Friedrich, 2012). In 1936 a ship sturgeon was caught in Vienna with a length of around 160 cm. The original text describes it as Russian sturgeon (Österreichs Fischereiwirtschaft, 1936) whereas Zauner (1997) correctively identifies it as ship sturgeon (Friedrich, 2012).

Nowadays only one of the five sturgeon species native in Austrian waters can still be found in small quantities, the sterlet (Friedrich, 2012).

Table 1: Characteristics of three morphologically different sections of the Austrian Danube. The numbers 3a, 3b and 4 refer to the division of the whole Danube (Schotzko & Wiesner, 2007, after Haunschmid et al., 2006).

River-km	**Section 3a: 2225-2001**	**Section 3b: 2225-2001**	**Section 4: 2001-1789,5**
Reach	Eastern Alpine Foothills Danube breakthrough sections	Eastern Alpine Foothills Danube anabranching sections	Lower Alpine Foothills Danube

Table 2: Reference fish communities of the three Austrian Danube sections (Schotzko & Wiesner (2007) after Haunschmid et al., 2006), d...dominant species, s...subdominant species, r...rare species.

Species name (acc. to Kottelat & Freyhof, 2007)	Section 3a	Section 3b	Section 4
Ballerus ballerus	r	s	d
Abramis brama	d	d	d
Abramis sapa	s	s	s
Acipenser gueldenstaedtii	r	r	r
Acipenser nudiventris	r	r	r
Acipenser ruthenus	r	r	r
Acipenser stellatus	r	r	r
Alburnoides bipunctatus	r	r	r
Alburnus alburnus	d	d	d
Alburnus mento	r	r	r
Aspius aspius	s	s	s
Barbatula barbatula	r	r	r
Barbus balcanicus	r	r	r
Barbus barbus	d	d	d
Blicca bjoerkna	s	s	s
Carassius carassius	r	s	s
Carassius gibelio	r	s	s
Chondrostoma nasus	d	d	d
Cobitis elongatoides	r	r	r
Cottus gobio	r	r	r
Cyprinus carpio	r	r	r
Esox lucius	s	d	d
Eudontomyzon mariae	r	r	r
Gobio gobio	r	r	r
Gymnocephalus baloni	r	r	r
Gymnocephalus cernua	r	r	r
Gymnocephalus schraetser	s	s	s
Hucho hucho	d	d	d
Huso huso	r	r	r
Leucaspius delineatus	r	r	r
Leuciscus idus	d	d	d

Species name (acc. to Kottelat & Freyhof, 2007)	**Section 3a**	**Section 3b**	**Section 4**
Leuciscus leuciscus	d	d	d
Telestes souffia	r	r	r
Lota lota	s	s	s
Misgurnus fossilis	r	r	r
Pelecus cultratus	r	r	r
Perca fluviatilis	s	s	s
Phoxinus phoxinus	r	r	r
Rhodeus amarus	r	s	s
Romanogobio kesslerii	r	r	r
Romanogobio uranoscopus	r	r	r
Romanogobio vladykovi	s	s	s
Rutilus meidingeri	r	r	
Rutilus virgo	r	r	r
Rutilus rutilus	s	s	s
Sabanejewia balcanica			r
Salmo trutta fario	r	r	r
Sander lucioperca	s	s	s
Sander volgensis			r
Scardinius erythrophthalmus	r	r	r
Silurus glanis	s	s	s
Squalius cephalus	s	s	s
Thymallus thymallus	r	r	r
Tinca tinca	r	r	r
Umbra krameri			r
Vimba vimba	s	s	s
Zingel streber	s	s	s
Zingel zingel	s	s	s

2.2.1 Description of selected Danube fish species as traded at the Viennese fish market

The present thesis is based on data from the Viennese fish market. Since the provenance of the fish is not indicated, an assumption had to be made which was ultimately proven correct as to which fish species originated from the Austrian Danube. These species are called in this thesis "potential Danube fish species" and their ecological characteristics are described below. According to the reference fish list of Schotzko & Wiesner (2007) and the literature analysis of historical sources (e.g. Krisch, 1900) 19 of the pure freshwater species from the Viennese fish market data can be considered as potential Austrian Danube fish species (Table 3) and well be described more in detail.

For the objective of this thesis neobiota, species that migrated or were introduced into the Danube after 1492 (Essl & Rabitsch, 2010) were not included into the list of Danube fish species (eel (*Anguilla anguilla)*, rainbow trout (*Oncorhynchus mykiss))*.

Table 3: List of potential Danube fish species delivered to the Viennese fish market (according to the reference list of Schotzko & Wiesner, 2007 and contemporary literature analysis).

- Barbel
- Bream
- Sterlet
- Bleak
- Blue bream (*Ballerus ballerus*)
- Crucian carp (*Carassius carassius*)
- Nase
- Pike (*Esox lucius*)
- Danube salmon
- Ide
- Burbot (*Lota lota*)
- Weatherfish (*Misgurnus fossilis)*
- Perch (*Perca fluviatilis*)
- Pikeperch (*Sander lucioperca*)
- Wels (*Silurus glanis*)
- Chub (*Squalius cephalus*)
- Tench (*Tinca tinca*)
- Stone loach *(Barbatula barbatula)*

The following description of the potential Danube fish species is based on different types of literature. Contemporary literature from the 19th century in the form of early fish ecological surveys (Heckel & Kner, 1858; Siebold, 1863), together with reports about fish trading (Peyrer, 1874) were used. Further fish ecological surveys from the 20th century and the present (Schotzko & Wiesner, 2007; Spindler, 1997; Schiemer et al., 1994; Wolfram & Mikschi, 2007 and Hauer, 2011) served as the fountation.

Human impacts on rivers, such as river regulation modify habitats and affect fish species with similar ecological features in similar ways. This is accounted for in the guild concept. One criterion to distinguish fish is for instance their preference for flow conditions (Schiemer & Waidbacher, 1992):

1. **(a) Rheophilic A species**: fish species, which need higher current during their whole life cycles (barbel and nase).
1. **(b) Rheophilic B species**: prefer basically higher currents as adults but require lower velocities as prevailing in side arms and backwaters during certain stages of their life cycle (e.g. ide and asp).
2. **Eurytopic species**: species that can adapt to different kinds of flow conditions and therefore colonize many habitats (e.g. chub, bleak and perch).
3. **Limnophilic or stagnophilic species**: backwater and stagnant water bodies are preferred habitats. Limnophilic species spend their whole life cycle in backwaters (limnophilic) and some can even survive periodically in anoxic conditions, e.g. as in dried out ponds (European weatherfish).

2.2.1.1 Cyprinidae

Cyprinids form the biggest group of the Danube fish (Schotzko & Wiesner, 2007). Historical sources of the 19th and the early 20th century, as the Viennese fish market registers, refer to many of them as the group of “whitefish” („Weißfische“). In an Imperial decree (Hofkammer-Dekret vom 28. August 1893, Z. 36.746) pronounced in 1839, for the taxation of freshwater fish, the following species were compiled under the collective term “whitefish”: chub, barbel, bream, bleak, nase, asp, sichel (*Pelecus cultratus*), ide (Krisch, 1900). Cyprinids are furthermore an important food source for some of the highly valued game fish, such as the Danube salmon, pike and pikeperch.

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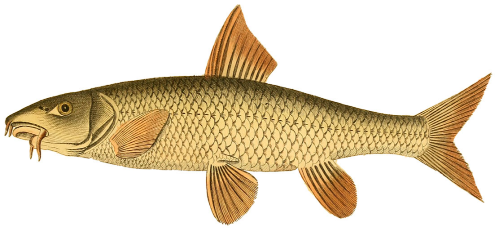

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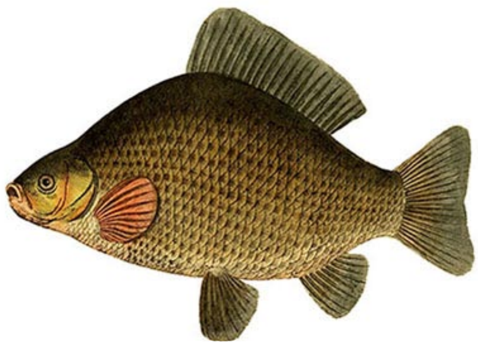

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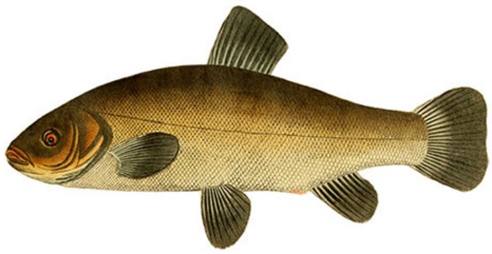

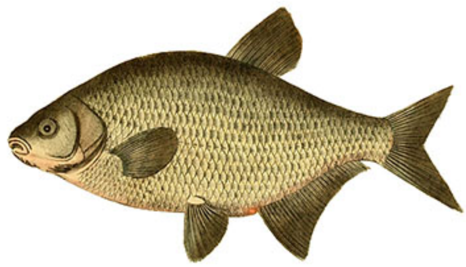

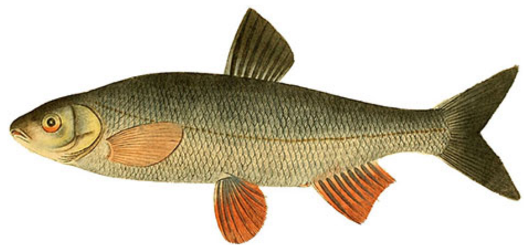

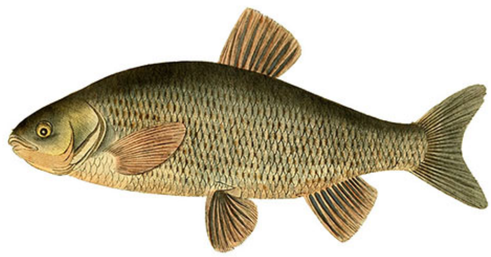

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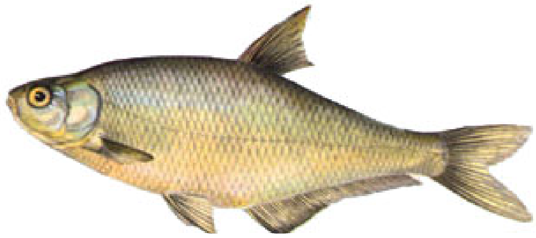

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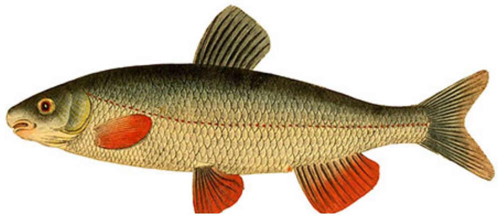

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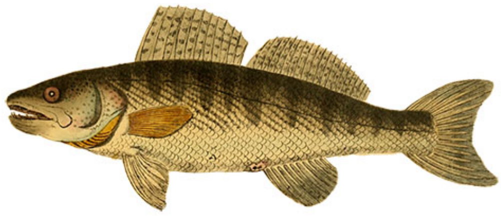

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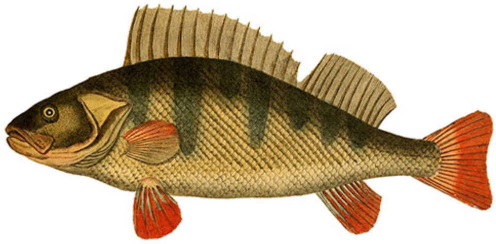
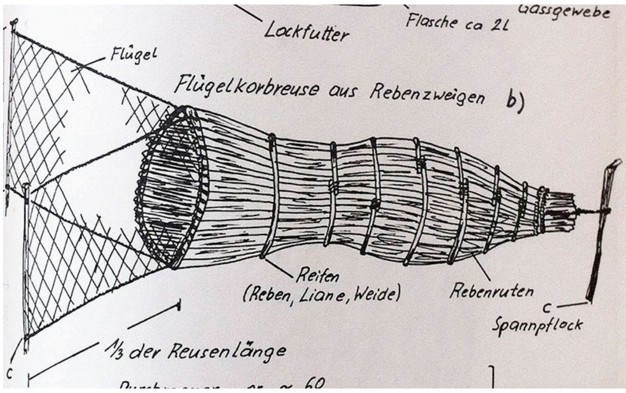


2.3 Commercial fishery in the Austrian Danube

Commercial fishery in the Austrian Danube had its heydays in the Middle Ages, at a time when also large belugas were fished, some of which reached lengths of up to 6 meters. Fishing was considered a craft, fishing guilds were formed and the knowledge was passed on from one generation to the other. In the late 19th century fishery was still important for the Austrian economy because it was one component of the primary production. It was considered to be entirely "natural", no factories were needed and fish was a delicious and easily digestible protein-source (Raab, 1978). Weber (1989) describes the Danube fishery as one of the oldest and most productive Viennese trades. Especially before the import of marine fish started in 1900, Peyrer (1874) points to the high importance of domestic waters as sources of nutrition. This demand decreased quickly with the availability of cheaper marine fish during the beginnings of the 20th century. During the end of the 19th century, fishery on the Danube declined and in the 20th century the total disappearance of the Danube fishermen in Austria took place. One of the last families of fishermen, Hammerschmidt, worked up to the 1970s, but by then it had already become quite hard to make a living out of it(Raab, 1978). Other families with a long tradition as fishermen in Lower Austria included Humer and Ahringer in Orth and Eckartsau and the family Kipferl in Petronell (Jungwirth, 1975). According to the "Approvisionirungs-Enquête" in 1871 (K.k. Handeslministerium, 1871) only 5 official Danube fishermen still existed at that time in Vienna. The guild of fishermen in Vienna was officially dissolved in 1872. This led to the downfall of professional fishing while at the same time a rise in recreational fishermen occurred (Weber, 1989). In the city of Krems, Lower Austria, six people were officially employed in the sector of fishery in 1874 (Krafft, 1874). Since the catch was very small the fishermen mainly lived from the trade with pond carps from Bohemia.

At the end of the 19th century and the beginning of the 20th century, the craft went through difficult times when confronted with the transformation of the Danube to a straightened river. These changes impacted the fish fauna drastically and improved the efforts to reduce the negative effects of fish exploitation. The training of fishermen was considered particularly important for the maintenance of the fish communities. Angling picked up especially after the World Wars and is still an important recreational activity at present. This fact is noted by the number of fishing licences issued in Lower Austria (§ 14 (1), NÖ FischG, 2001). In 1948 a total of 2782 fishing licences ("Fischerkarten") were handed out, in 1973 the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3 Material and methods

The following chapter describes the material and methods used in this thesis. Basically, the documents used in this thesis were fish market registers (from 1881-1914), contemporary literature, such as fisheries journals, protocols from the Danube Regulation Commission, and reports from fishermen and traders at the fish market (Krisch, 1900). Furthermore, early scientific fish ecological surveys such as the descriptions of the fish fauna from Siebold (1863) were also consulted.

Apart from the written documents, cartographic material proved to be of great importance. A major part of the thesis was indeed the preparation and interpretation of the historical maps, often involving different scales, techniques and styles, for additional analyses. Moreover visual material such as paintings and pictures were considered. The historical sources stem from various libraries, federal-, provincial- and city archives (e.g. for historical maps the Federal Office for Metrology and Surveying in Vienna (BEV)).

3.1 Source critique

Historical sources were not recorded or published specifically to document fish-ecological conditions but instead were for statistical-, tax- or organizational purposes and various others. A historical source in a strict sense is anything that has been left behind by the past (Cambridge Faculty of History, 2014). All the historical sources used in this thesis needed further analyses and evaluation to obtain knowledge about fish composition, river regulation and commercial fishing practices. This enabled adequate assumptions about the ecological information in the historical sources (Haidvogl et al., 2014).

3.2 Fish market data

Until the second half of the 20th century fish ecological investigations hardly existed. For that reason, other sources had to be used to reconstruct the Danube's past fish composition. For the Austrian Danube yearly statistics of the Viennese fish market data are a valuable quantitative source already made available from former research (Haidvogl et al., 2014; Haidvogl & Pont, 2013). The records cover a period of five decades from 1867 to 1914. Consistent and detailed data were only available however, from 1881 to 1914. Older records were very rare. An exception are data for the years 1868-1870 from the „Wiener Approvisionirungs-Enquête“ in 1871 (K.k Handelsministerium, 1871). The statistics of the

Viennese fish market comprise always yearly, sometimes also monthly and even weekly data. Fish market registers included the amount of one species in kilograms, which was delivered to the market. Consequently information about increasing or decreasing deliveries for a specific fish species at a certain time was available and recorded into an EXCEL database. The likely provenance of the different species was indicated (see below).
The Viennese fish market data were found in different sources such as the Mitteilungen des österreichischen Fischereiverbandes (MiöFV), Österreichs Fischereiwirtschaft, in a publication of the commission for tax issues (Approvisionirungs-Enquête, K.k. Handelsministerium, 1871) and in the statistical yearbook of the city of Vienna (Statistisches Jahrbuch der Stadt Wien).

The main sources for the data were:

- Handwritten forms of the statistics from 1881 to 1893 and from 1895 to 1897 (Library of Vienna (Wienbibliothek))
- Statistisches Jahrbuch der Stadt Wien: annual statistics of the fish market for 1894 and from 1898 to 1914 (National library of Austria (Annokatalog))
- Mitteilungen des österreichischen Fischerei-Verbandes (MiöFV): weekly reports from the fish market Vienna 1899 to 1903
- Österreichs Fischereiwirtschaft (former MiöFV): weekly data for the fish market for 1904, 1908 and 1913; and annual data from 1867 to 1871

The provenance of fish is one key factor for the analysis of the fish market data and their possible link to the fish composition of the Austrian Danube. The origin of the (freshwater-) fish species has to be known in order to distinguish between deliveries from the Austrian Danube, and other Danube sections, tributaries, fish farms or lakes. Especially until the 19th century, details about the provenance of fish can often be found in fish trading laws and in documents of fish traders (e.g. guild records, Haidvogl et al., 2014). A classification for the probable origin of the fish species was developed. Most important for the analysis but also in terms of amounts delivered were the potential Austrian Danube fish, marine fish and farmed fish. Less important categories in terms of amounts were fish from tributaries (mainly trout and char) as well as fish from lakes and non-Danube diadromous and freshwater fish (e.g. salmon, eel, lampreys, shads). The classification contains the following categories:

- Potentially Austrian Danube (e.g. bream, ide, barbel, tench, “whitefish”)
- Potentially Hungarian Danube (e.g. Beluga sturgeon)
- Mainly farmed fish (e.g. carp)
- Mainly Danube tributaries (e.g. brown trout (*Salmo trutta fario)*, rainbow trout, artic and brook char (*Salvelinus sp*.))
- Non-Danube fish (salmon (*Salmo salar)*, eel, shad (*Alosa alosa)*, European sturgeon (*Acipenser sturio*))
- Lake fish (e.g. pike from lakes, trouts from lakes (*Salmo trutta lacustris*))
- Marine fish (e.g. Atlantic cod (*Gadus morhua)*, Atlantic halibut (*Hippoglossus hippoglossus*))

For the Viennese fish market the decision regarding the provenance of the 65 fish species delivered during the studied period was taken in line with the assumption in contemporary literature (e.g. Krisch, 1900, see Table 9, p. 54) and the defined classification. Among them were 27 pure freshwater species, 7 migratory species (e.g. salmon) and 31 marine species. 19 potential Danube fish species could be classified including the “whitefish”, a category of cyprinid fish (Table 4).

Table 4: The 19 potential Danube fish species, including “whitefish” as category for cyprinid fish and their ecological guilds (after Schiemer & Waidbacher, 1992).

Ecological guild	Species
eurytopic	Bream
	Pike
	Bleak
	Wels
	Pikeperch
	“Whitefish”
	Perch
rheophilic A	Barbel
	Danube salmon
	Chub
	Sterlet
	Nase
	Stone loach
rheophilic B	Ide
	Blue bream
	Burbot
limnophilic	Crucian carp
	Tench
	European weatherfish

3.2.1 **Identifying potential Danube species**

The identification of potential Danube fish species delivered to the Viennese fish market was first based on contemporary literature as explained above. Furthermore, apart from the meticulous use of historical resources, the classification of potential Danube species required a profound knowledge of the time (1867-1914), the place (Austrian Danube) and of the changes in the taxonomy of the fish. Difficulty arises when it comes to different local terms for fish species. The pikeperch, for instance, appears in the data as "Schill", "Fogosch", "Zander" and "Schiel". In addition "Schiel" can be confused with "Schied", the asp (*Aspius aspius*). Some of the commercially important fish were not recorded on species level. This holds true for a group of cyprinid species, which were sold as "whitefish" ("Weißfische") (Raab, 1978). Afterwards, monthly delivery data for single species were used as a further indicator. For the studied period monthly data was available for the years 1881 to 1893 and for 1904 to 1914. In order to confirm the pre-selection of the potential Danube species two assumptions were made: Danube fish species were subject to the fishery laws of Upper and Lower Austria and therefore closed seasons had to be obeyed; in that case, potential Danube fish should not appear in the months when their catch was forbidden. It has to be noted here, that the different fish species can stem also from tributaries but the list of potential Danube fish comprises mainly of epipotamal species, which occur at the utmost in the lower sections of the larger tributaries such as the river Traisen or Traun. For most of the species, there are significant changes in the delivery during the investigated period (as shown in the yearly data). For the analysis of the seasonal variability of the delivery, the between-year variability had to be removed. Hence for a given species (s) and a given year (y), each single value (month) was transformed. They were divided by the annual delivery for the considered year (y) of the species (s) and multiplied by the mean annual delivery of the species (s). When a fish species was absent, i.e. not delivered to the market during their closed season, it was assumed that the fish were from the Danube since – as mentioned above - the potential Danube fish species were typical for epipotamal rivers. Closed seasons were defined in the fishery law from 1891 for Lower Austria (NÖ LGBl. 1891/2) and in 1895 for Upper Austria (OÖ LGBl. 1895/48) but they existed much longer due to earlier regulations. These laws also regulated the fishing season and when the fish could be sold on the market or in other places. In addition, minimum sizes for certain fish species were defined. Table 5 shows the closed seasons as they were stated in the law from 1891 for Lower Austria in

Krisch (1900). For reference and orientation the closed season from Upper- and Lower Austria nowadays were compared with the historical data (see Table 6).

Table 5: Closed seasons as defined in the fishing laws for Lower Austria (NÖ LGBl. 1891/2) and Upper Austria (OÖ LGBl. 1895/48) (after Krisch, 1900).

Species	Closed season	Fishing season	Selling time	Min. length
Barbel	16.5. -15.6.	16.6. -15.5.	16.6. -18.5.	Min. body
Bream	1.5. -31.5.	16.12. -15.10.	16.12. -18.10.	length; from
Pike	1.3. -31.3.	1.4. - ultimo Febr.	1.4. -3.3.	the top of the head till the
Danube salmon	16.3. -30.4.	1.5. -15.3.	1.5. -18.3.	end of the vertical fin
Bleak	1.5. -31.5.	1.6. -30.4.	1.6. -3.5.	ide, trout, barbel, bream,
Nase	1.5. -31.5.	1.6. -30.4.	1.6. -3.5.	nase: 25 cm sterlet: 30 cm
Ide	1.5. -31.5.	1.6. -30.4.	1.6. -3.5.	pikeperch, pike:
Sterlet	1.5. -30.6.	1.7. -30.4.	1.7. -3.5.	35 cm wels, Danube
Wels	1.6. -30.6.	1.7. -31.5.	1.7. -3.6.	salmon: 40 cm
Pikeperch	16.4. - 31.5.			

Table 6: Closed seasons as defined in present fishery laws from Upper Austria (OÖ LGBl. Nr. 97/1983 Abschnitt V., § 12) and Lower Austria (NÖ FischG, 2002, LGBL. 6550/1 §10) in comparison with the historical closed seasons from Upper (OÖ LGBl. 1895/48) and Lower Austria (NÖ LGBl. 1891/2).

Species	Closed season Upper Austria	Closed season Lower Austria	Historical closed season
Chub	none	none	
Barbel	01.05.-15.06.	01.05.-15.06.	16.5.-15.6.
Bream	01.05.-31.05	01.05.-31.05	1.5.-31.5.
Perch	none	01.03.-31.05.	
Pike	01.02.-30.04.	01.02.-30.04.	1.3.-31.3.
Danube salmon	16.02.-15.05.	01.03.-31.03.	16.3.-30.4.
Crucian carp	whole year	01.05.-31.05.	
Carp	01.05.-31.05.	none	
Bleak	15.05.-30.06.	16.05.-30.06.	1.5.-31.5.
Nase	16.03.-31.05.	16.03.-31.05.	1.5.-31.5.
Ide	whole year	01.05.-30.06.	1.5.-31.5.
Roach	01.04.-31.05.	01.04.-31.05.	
Asp	16.04.-31.05.	16.04.-31.05.	
Tench	16.05.-30.06.	01.06.-30.06.	
Sterlet	01.05.-30.06.	01.05.-30.06.	1.5.-30.6.
Wels	01.06.-30.06.	01.06.-30.06.	1.6.-30.6.
Pikeperch	01.04.-31.05.	01.04.-31.05.	16.4.-31.5.

3.2.2 Analyzing changes in delivery of fish species

In a subsequent step for the potential Danube species the annual amounts delivered – given as weight in kg/ year - to the fish market were analyzed to identify changes. The total weight in kg per year and fish species was also used for the statistical test of the link between a change in the fish delivery and in the habitat conditions (due to hydraulic structures).

3.3 Commercial fishery practices

The literature analysis of commercial fishery and their practices in the Austrian Danube was based on printed writing such as:

- Contemporary literature, statistics and laws commissioned by the state
- Historical studies from the 20th century dealing with the history of Danube fishermen, as the work of Jungwirth (1975), Raab (1978) and Jungwirth (2001).

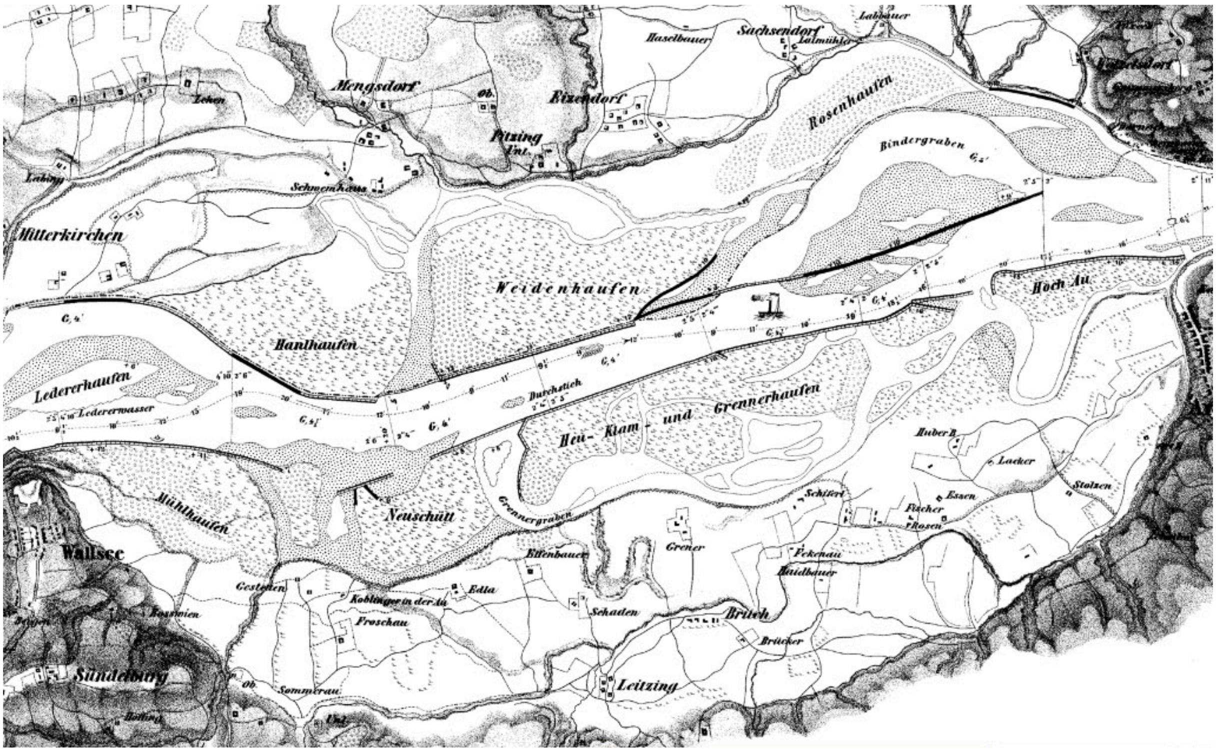
Raab (1978) focuses on the Danube in Lower Austria and the traditional family of fishermen Hammerschmidt. Jungwirth (2001) examines the Danube in Upper Austria, specifically the Eferdinger Becken. Many articles refer to a decrease of commercial fishery due to different factors among them steam ships, river straightening, exploitation of the fish and industrialization. Yet no direct relation between the hydromorphological changes, channelization, and the fishery practice in the Austrian Danube were found. Therefore we assumed that there were at least no fundamental changes of fishing practices and no further analyses were conducted.

3.4 Historical Maps

Historical maps can be used to analyze anthropogenic changes in the aquatic habitat composition of a river. Furthermore, some historical maps include the river engineering works that had major impacts on the biocoenosis (Weber et al. 2007, for the Swiss Rhône). The studied period covers the situation of only small-scale and local regulations up to the complete channelizing of the Austrian Danube. To link the change in the fish species delivered to the Viennese fish market with the systematic river channelization occurring at that time, the alluvial basins, in particular, were considered because they went through drastic changes. Before 1865 the river consisted of a highly complex channel network with a high number of gravel bars and extensive islands (Hohensinner et al., 2004).

For this thesis maps from the middle of the 19th century to the beginning of the 20th century were chosen to analyze hydraulic structures, e.g. alterations of the aquatic habitats due to regulation works, in the Austrian Danube. Places where the maps are kept were the Austrian State Archives (Pasetti map) and the Federal Office of Metrology and Surveying, Vienna (BEV) (Francisco-Josephinische Landesaufnahme, Faltbootführer). Several visits to the BEV made it possible to investigate the maps showing the Danube in detail. One significant point lies in the "evidence map" of the 2nd map, the Francisco-Josephinische Landesaufnahme, whose true year of regulation measures was added after the original map was prepared (see Appendix, Findings of the Evidence Map, p. 110).

The maps were processed using ArcGIS and a database was prepared in Microsoft EXCEL, based on former research by Hohensinner et al. (2013). The maps used were geometrically corrected using present topographic maps and still existing landmarks for orientation. Afterwards the maps were vectorized. In terms of source critique, it has to be noted that the maps were not created for an analysis in the future, but for a specific purpose at the time (Hohensinner et al., 2013). Source critique was necessary to process these data and get useful results, as in some cases the names of places were exchanged, and hydraulic structures were added afterwards (e.g. 3rd Military Survey and its evidence maps). Written sources were of great importance to support the mapping process. Specifically details to define the construction date for the hydraulic structures were needed. Literature mostly yielded insights into the construction periods (e.g. 20 years) but not a precise year. Still, important information about the development of the construction methods during the studied period could be gained to classify between four major periods. The literature


Mengsdorf
Sachsendorf
Haselbauer
Eizendorf
Pitzing
Rosenhaufen
Bindergraben
Lehen
Mitterkirchen
Weidenhaufen
Hanlhaufen
Ledererhaufen
Ledererwasser
Hoch Au
Durchstich
Heu- Klam- und Grennerhaufen
Mühlhaufen
Neuschütt
Grennergraben
Wallsee
Sindelburg
Gestetten
Froschau
Edla
Schaden
Grener
Haidbauer
Leitzing
Sommerau
Lacker
Stolzen
Essen
Fischer
Rosen

works. Due to this detailed map, in some cases even the exact construction date and the consequences on fluvial processes were able to be determined (Hohensinner et al., 2013).

3.4.2 Francisco-Josephinische Landesaufnahme

The 3rd Military Survey (Francisco-Josephinische Landesaufnahme) was used for the second time period from 1869 to 1887. On the 24th of April 1869 Emperor Franz Joseph I. gave the order for a new land survey, with the name Francisco-Josephinische Landesaufnahme (Fig. 28). More than 330 draftsmen worked on the production of 752 sheets of the new "*Spezialkarte 1:75000"* of the Austro-Hungarian Empire. For the coloured map sheets, the scale 1:25 000 was in use and for the area around Vienna 47 sheets with the scale 1:12 500 were drawn. This work was accomplished in only 18 years, a true masterpiece and role model in the history of cartography. It was recognized in all countries around the world (Bundesamt für Eich- und Vermessungswesen, 2010).

Figure 28: Detail of the Francisco-Josephinische Landesaufnahme (1872-1875) in the basin stretch Machland (BEV).

3.4.3 Karte der österreichischen Donau

The "Faltbootführer" ("Karte der österreichischen Donau") – a map prepared for the use of private boatmen - was utilized to cover the time period from 1910 to 1916. The navigation map focused on the main arm of the channel and only showed a small strip of the adjacent land (Fig. 29) in the scale of 1: 10 000. The navigation line and the newly constructed low flow regulation were marked to help navigate on the Danube. The map is available as a Leporello fold and was commissioned by the Federal Ministry of Trade and Traffic (Bundesministerium für Handel und Verkehr).

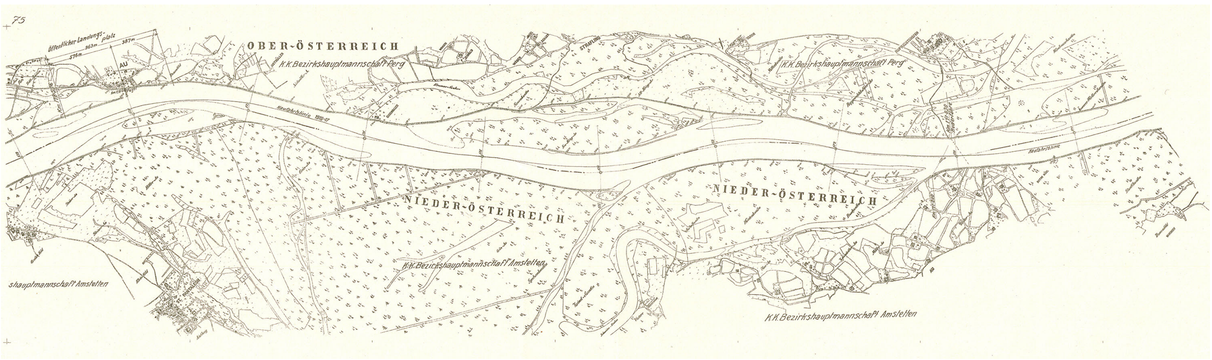


Figure 29: Detail of the Faltbootführer (1910) in the basin stretch Machland (BEV).

3.4.4 Österreichische Karte

The present topographic map of Austria (ÖK 50) (Fig. 30) in the scale of 1: 50 000 was used as reference for the historical maps. It was created in 2010.

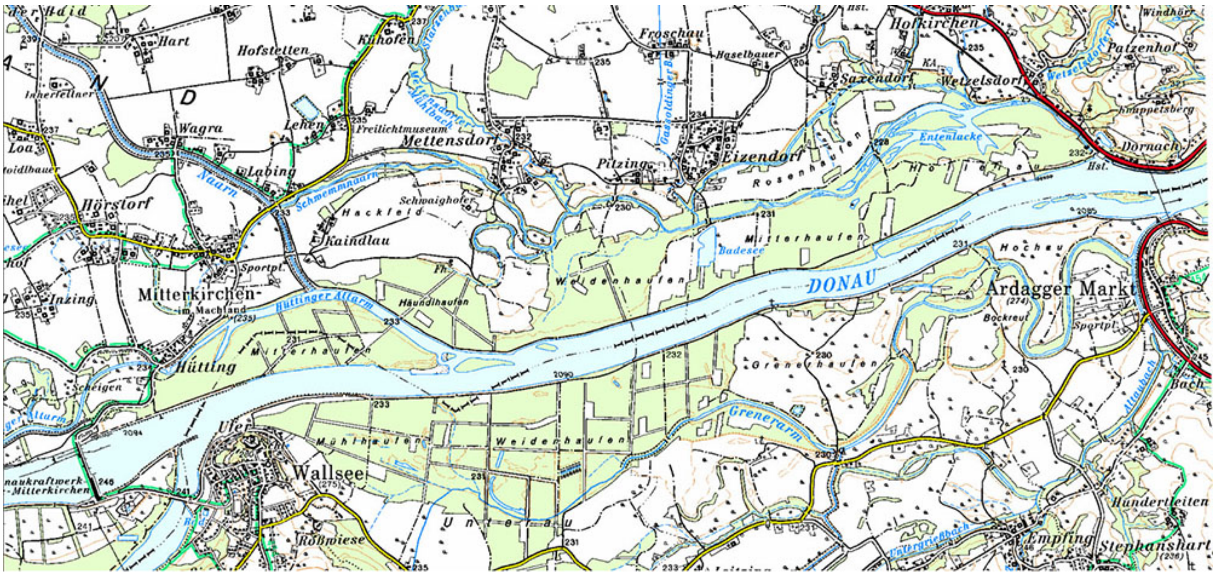


Figure 30: Detail of the current map of Austria (ÖK 50) in the basin stretch Machland (BEV).

The classification of the maps into three time periods had to be adjusted to the literature analysis and the findings in the “evidence map” (see Appendix, p.110) and the data from the Viennese fish market registers.

1st map Pasetti map:	1857 – 1867	- ►	1860 – 1867
2nd map 3rd Military Survey:	1869 – 1887	- ►	1875 – 1892
3rd map Faltbootführer:	1910 - 1916	- ►	1893 – 1910

3.5 Georeferencing of historical maps

The georeferencing of historical maps allows comparing past and present situations, which is furthermore known better than in the past. When a sequence of historical maps is used, it is recommended to proceed from the better known to the lesser known situation. Georeferenced ArcGIS raster-data of the Austrian map (ÖK 50, 2010), with defined geodesic system were used to start the referencing-process of the historical maps. The spatial reference system was a “Transverse Mercator-Projection”, in Austria based on an optimized Bessel-Ellipsoid. The 2nd map was already available as georeferenced raster data set. Pasetti map and Faltbootführer were available in raster format (TIFF, JPG). This format had no scale or coordinate system. Therefore the maps were imported into the geoinformation software ArcGIS 10.2. With this program it was possible to georeference single map sheets. Control points connecting the historical and current maps spatially were used, as they are the most common method (Piller, 2012).

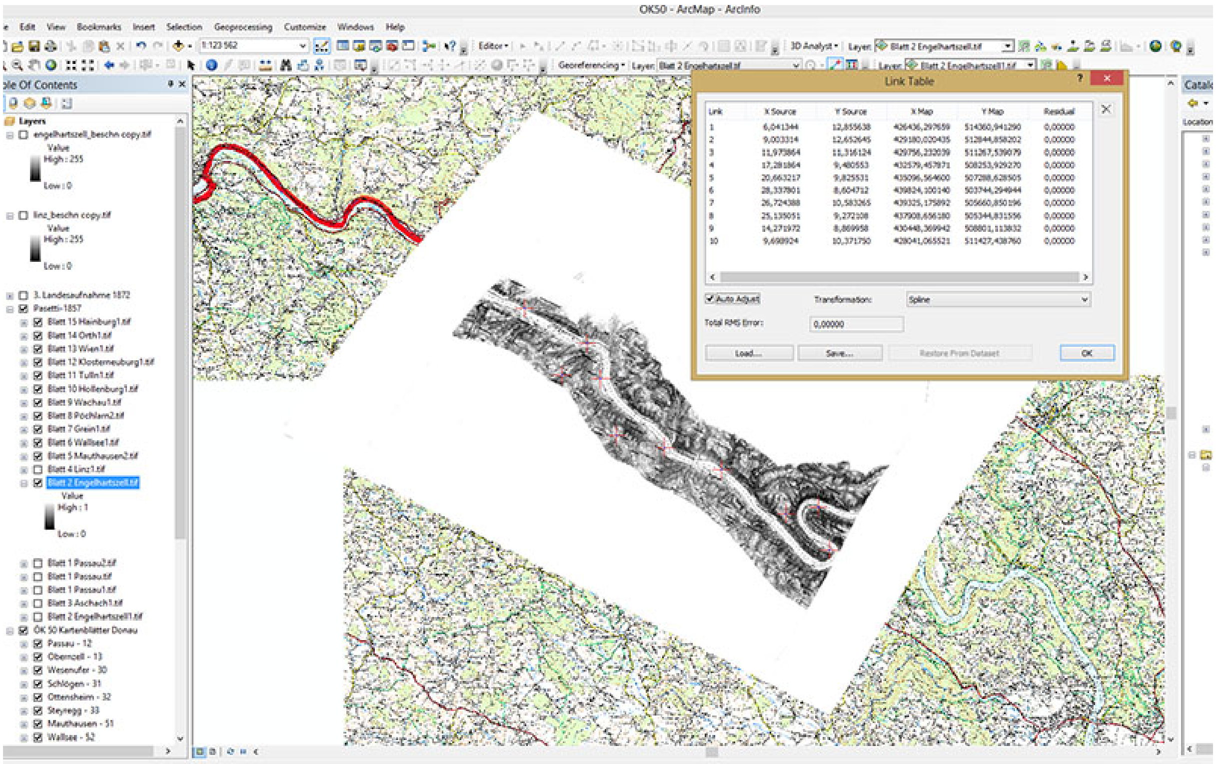
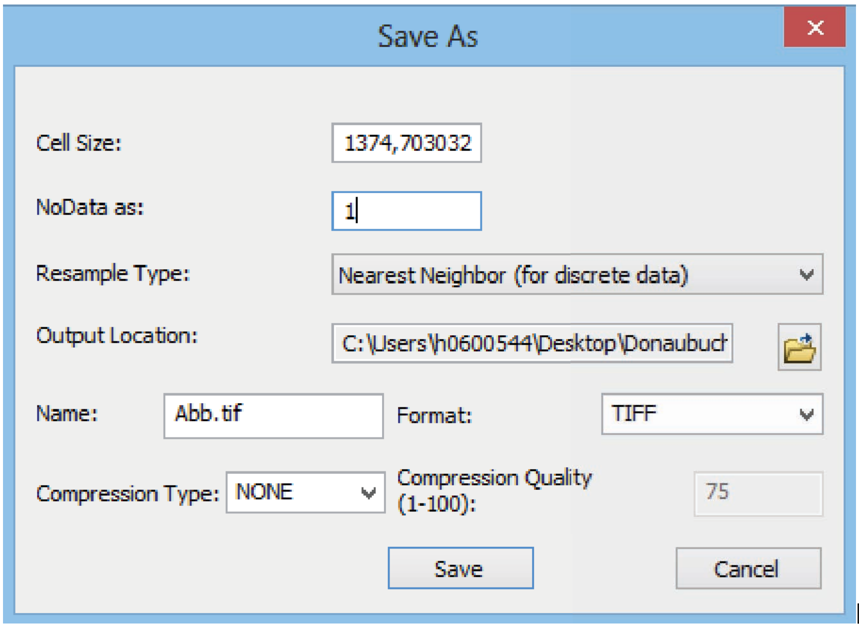


Figure 31: Georeferencing process in ArcGIS: setting of control points with the reference map ÖK 50 for the Pasetti map (author).

Often three control points are sufficient for accurate georeferencing, but as a result of high inaccuracy, a minimum of 10 control points per map-sheet was necessary. In most cases 40 and more control points were set to guarantee precise results. More control points were necessary as historical maps were less accurate than modern ones, especially in wide



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Cell Size:
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NoData as:
1
Resample Type:
Nearest Neighbor (for discrete data)
Output Location:
C:\Users\h0600544\Desktop\Donaubuch
Name:
Abb.tif
Format:
TIFF
Compression Type:
NONE
Compression Quality (1-100):
75
Save
Cancel

3.5.2 Georeferencing of Faltbootführer

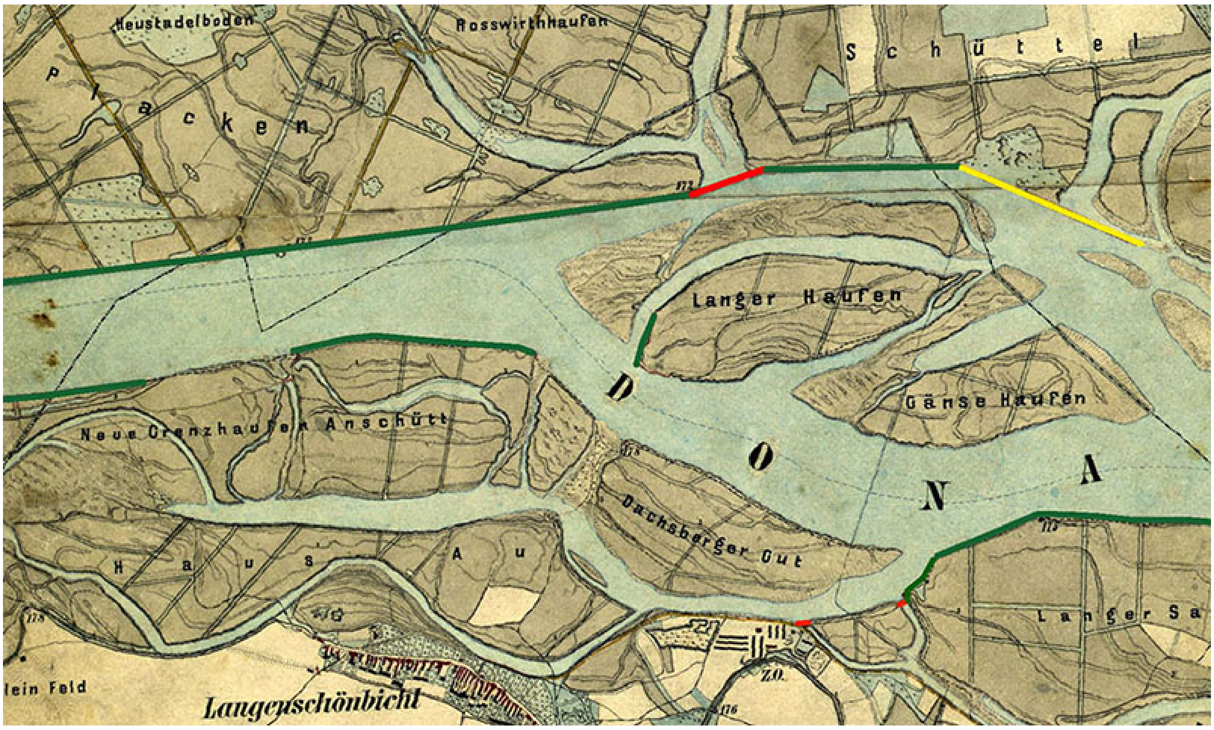
The Austrian Danube area is split into 28 parts from the Austrian border with Germany to the border with Slovakia at Theben (Devin) in the Faltbootführer. To prepare the scanned pictures for ArcGIS georeferencing, the cut-out parts needed to be connected. This was done in Adobe Photoshop CS6 via masks and exporting the pictures as TIFF with LZW-compression. They could then be imported into ArcGIS for the referencing.

3.6 Mapping hydraulic structures and lateral connectivity

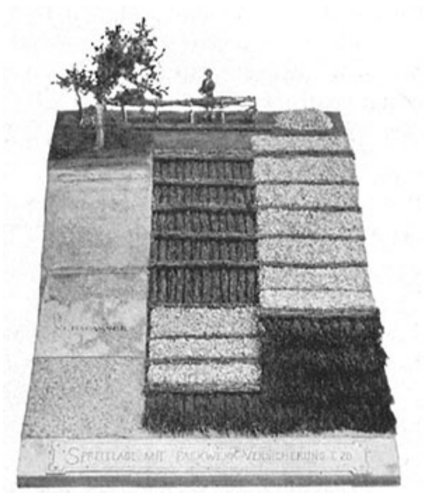
3.6.1 Reconstructing hydraulic structures

Apart from the effects of floods changes in the hydromorphology of the Danube occurred in the investigated period mainly due to the erection of hydraulic structures (regulations) along the river. For the reconstruction of anthropogenic alterations along the river system the following types were defined:

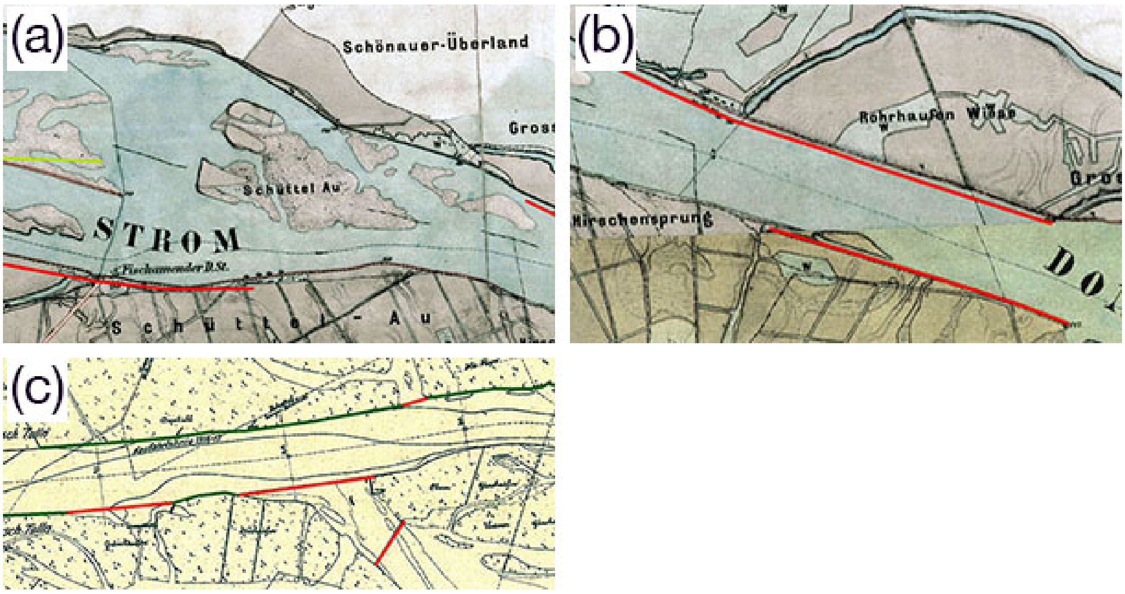
- **Closure dams/levees** (acc. to Pinkard & Stewart, 2001) are all closings of side arms, backwaters or interruptions of water flows. They result in the decoupling of water bodies through the engineering works. The impact on fish is owed to blocked migration routes and interrupted access to different aquatic habitats, depending on the flow conditions (Fig. 33, red line).
- **Training walls/guiding walls** act as guidance structures for the river and favor aggradation. Their main purpose is to gain land behind the walls and to channelize the river. In the beginning, training walls enable different flow conditions within the riverbed, especially in combination with groynes. Yet they transform the river into a homogenized stream with little habitat diversity over time. Side arms which provide food sources, winter refuge and spawning grounds are more difficult to access and accelerated aggradation processes lead this system of backwaters and side arms to dry out (Fig. 33, yellow line).
- **Bank regulations** feature paved banks for the purposes of preventing erosion, facilitating the transport of ice and increasing the discharge. Yet such stabilization measures ultimately destroy the banks and adjacent vegetation. Fish lose shading structures. Paved banks (rip-rap) destroy the spawning grounds of many fish species,


Heustadelboden
Rosswirthhaufen
S c h ü t t e l
P l a c k e n
Langer Haufen
Gänse Haufen
D O N A
Neue Grenzhaufen Anschütt
Ochsberger Gut
H a u s A u
L a n g e r S a
lein Feld
Langenschönbicht
Z.O.

Modell eines Uferdeckwerkes.



Modell einer Faschinenspreitlage.


(a)
Schönauer-Überland
Schüttel Au
STROM
(b)
Hirschensprung
(c)

[illegible]

65 [illegible]

[illegible]

[illegible]

	A: Id	B: Type	C: Length	D: watertype	E: curren	F: past	G: stretch	H: basinwidt	I: reglength	J: length(km)	K: Basin_name	L: Lan	M: Map	N: Year	O: Columı	P: Auswertung
75	1	Damm	152,0148847	ParaB-EuB	ParaB		Beck	e	>1	0,15	Wiener Becken	NOE	Pasetti	1850-1867		186
76	1	Damm	53,4355365	ParaB-EuB	ParaB		Beck	e	>1	0,05	Tullnerfeld	NOE	Pasetti	1850-1867		186
77	1	Damm	66,14596563	ParaB-EuB	ParaB		Beck	e	>1	0,07	Tullnerfeld	NOE	Pasetti	1850-1867		186
78	1	Damm	960,3949529	ParaB-EuB	ParaB		Beck	b+400	>1	0,96	Tullnerfeld	NOE	Pasetti	1850-1867		186
79	1	Damm	180,5785367	ParaB-ParaA	ParaB		Beck	e	<1	0,18	Machland	OOE	Pasetti	1850-1860		186
80	1	Damm	256,2149721	ParaB-ParaA	ParaB		Beck	b+400	>1	0,26	Pöchlarn	NOE	Pasetti	1850-1867		186
81	1	Damm	62,89086616	ParaB - EuB	ParaB		Beck	b-400	>1	0,06	Machland	OOE	Pasetti	1850-1860		186
82	1	Damm	68,79983303	EuB-ParaB	ParaB		Beck	b+400	<1	0,07	Machland	NOE	Pasetti	1850-1867		186
83	1	Damm	130,2924419	Para B - Eu B	ParaB		Beck	e	>1	0,13	Eferdinger Beck	OOE	Pasetti	1850-1860		186
84	1	Damm	215,4543814	Para B - EuB	ParaB		Beck	e	>1	0,22	Eferdinger Beck	OOE	Pasetti	1850-1860		186
85	1	Damm	286,3868243	Para B - EuB	ParaB		Beck	b-400	>1	0,29	Eferdinger Beck	OOE	Pasetti	1850-1860		186
86	1	Damm	151,530576	Para B - EuB	ParaB		Beck	e	<1	0,15	Machland	OOE	Pasetti	1850-1860		186
87	1	Damm	284,5353113	Para B - EuB	ParaB		Beck	b-400	>1	0,28	Machland	OOE	Pasetti	1850-1860		186
88	1	Damm	289,317289	Para B - Para	ParaB		Beck	e	>1	0,29	Eferdinger Beck	OOE	Pasetti	1850-1860		186
89	1	Damm	110,6966698	Para B - Para	ParaB		Beck	b-400	>1	0,11	Eferdinger Beck	OOE	Pasetti	1850-1860		186
90	1	Damm	59,69284022	ParaB - EuB	ParaB		Beck	e	<1	0,06	Machland	OOE	Pasetti	1850-1860		186
91	1	Damm	569,7825227	ParaB - EuB	ParaB		Beck	b+400	>1	0,57	Machland	OOE	Pasetti	1850-1860		186
92	1	Damm	411,8376513	ParaB - EuB	ParaB		Beck	b-400	>1	0,41	Machland	OOE	Pasetti	1850-1860		186
93	1	Damm	107,7022079	ParaB - EuB	ParaB		Beck	b-400	<1	0,11	Machland	OOE	Pasetti	1850-1860		186
94	1	Damm	146,9572229	ParaB - EuB	ParaB		Beck	e	<1	0,15	Machland	OOE	Pasetti	1850-1860		186
95	1	Damm	89,05173155	ParaB-EuB	ParaB		Beck	e	>1	0,09	Tullnerfeld	NOE	Pasetti	1850-1867		186
96	1	Damm	815,6430564	ParaB-EuB	ParaB		Beck	b+400	>1	0,82	Tullnerfeld	NOE	Pasetti	1850-1867		186
97	1	Damm	277,3796189	ParaB-EuB	ParaB		Beck	b-400	<1	0,28	Wiener Becken	Wien	Pasetti	1857-1867		186
98	1	Damm	267,844336	ParaB-EuB	ParaB		Beck	e	>1	0,27	Tullnerfeld	NOE	Pasetti	1850-1867		186
99	1	Damm	65,45443272	ParaB-EuB	ParaB		Beck	b-400	>1	0,07	Machland	OOE	Pasetti	1850-1860		186
100	1	Damm	52,71796114	ParaB-EuB	ParaB		Beck	b-400	>1	0,05	Machland	OOE	Pasetti	1850-1860		186
101	1	Damm	79,77104728	ParaB-EuB	ParaB		Beck	b-400	>1	0,08	Machland	OOE	Pasetti	1850-1860		186
102	1	Damm	78,21902047	ParaB-EuB	ParaB		Beck	e	>1	0,08	Machland	OOE	Pasetti	1850-1860		186
103	1	Damm	68,28109336	ParaB-EuB	ParaB		Beck	b-400	>1	0,07	Machland	OOE	Pasetti	1850-1860		186

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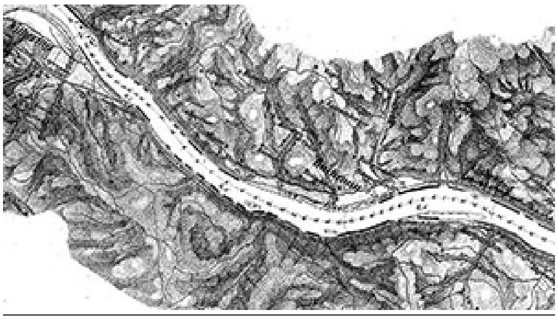


Figure 37: Natural boundaries in the breakthrough stretches (BEV).

One-sided regulations were not included into the analysis. Individual regulations on one side of the bank were characteristic for the regulation period until 1870. They were mainly made to fix riverbanks and to protect settlements from erosion, but not to detach the floodplains from the main channel. It can be assumed that the strongest changes in the aquatic habitats took place in the basin stretches with a river width of less than 400 meters and regulations on both sides of the banks (characteristic for river channelization at summer mean water level). The impact was intensified when the regulations were longer than 1 km. For the further analysis, 6 parameters were investigated for each basin (bank protections <1 and >1, closure dams <1 and >1, training walls <1 and >1) (see Table 7). In the Eferdinger Becken, only 5 parameters were used for further analyses as closure dams <1 were missing in this stretch. 24 variables were generated for the hydraulic structures in all four basin stretches, including the sum of all regulations in the respective basins. The dataset was built in MS Excel for easy adjustments and changes. In total 24580 hydraulic structures were mapped in the three maps (16077 in basin and 8503 in breakthrough sections). This would result in 12 hydraulic structures per km and per map, considering that the structures were situated on both sides of the riverbanks.

Table 7: Parameters recorded for the hydraulic structures of the 4 basin stretches. B= bank protection, T= training wall, C= closure dam, b-400 = river width less than 400 m and hydraulic structures on both banks, <1 = less than 1 km consolidated length, >1= more than 1 km consolidated length.

Basin stretches	Parameters	ID
Eferdinger Becken	Bank protection less than 1 km	Eb-400<1B
Eferdinger Becken	Training wall less than 1 km	Eb-400<1T
Eferdinger Becken	Closure dam more than 1 km	Eb-400>1C
Eferdinger Becken	Bank protection more than 1 km	Eb-400>1B
Eferdinger Becken	Training wall more than 1 km	Eb-400>1T
Machland	Closure dam less than 1 km	Mb-400<1C
Machland	Training wall less than 1 km	Mb-400<1T
Machland	Bank protection less than 1 km	Mb-400<1B
Machland	Closure dam more than 1 km	Mb-400>1C
Machland	Training wall more than 1 km	Mb-400>1T
Machland	Bank protection more than 1km	Mb-400>1B
Tullnerfeld	Closure dam less than 1 km	Tb-400<1C
Tullnerfeld	Trainin wall less than 1 km	Tb-400<1T
Tullnerfeld	Bank proctection less than 1 km	Tb-400<1B
Tullnerfeld	Closure dam more than 1 km	Tb-400>1C
Tullnerfeld	Training wall more than 1 km	Tb-400>1T
Tullnerfeld	Bank protection more than 1km	Tb-400>1B
Wiener Becken	Closure dam less than 1 km	Wb-400<1C
Wiener Becken	Training wall less than 1 km	Wb-400<1T
Wiener Becken	Bank protection less than 1 km	Wb-400<1B
Wiener Becken	Closure dam more than 1 km	Wb-400>1C
Wiener Becken	Training wall more than 1 km	Wb-400>1T
Wiener Becken	Bank protection more than 1 km	Wb-400>1B
Sum of regulations		Summe Reg

3.6.2 Aquatic Habitat

One additional feature was mapped for the hydraulic structures of closure dams, i.e. the aquatic habitat behind the structure, which was thereafter disconnected. Throughout the regulation process the aquatic habitat composition was altered and as a result also the fish assemblage. The aquatic habitats were mapped for all water bodies which divert from the main channel and were altered by closure dams. Connected and disconnected side arms, backwaters and oxbows were analyzed. Consequently it was possible to estimate the habitat change, e.g. in 1867 (Pasetti map) a closure dam separates a side arm from the main channel and transforms it into a backwater that is open only at the downstream end (see Fig. 38). In addition an aquatic habitat turnover rate could be calculated for modified water bodies for the three observed times (1867, 1892, 1910).

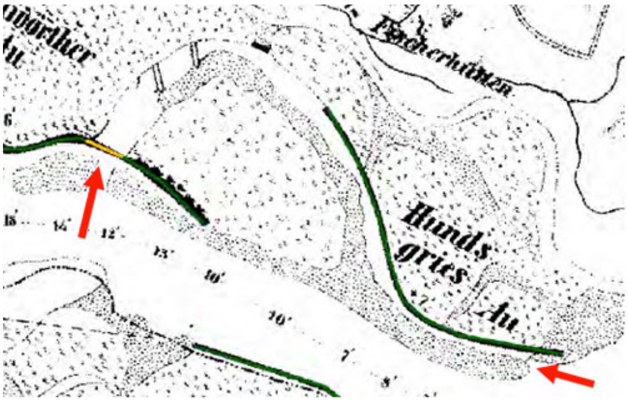


Figure 38: Transformation of a side arm into a backwater due to a closure dam around 1867 (author/BEV).

To analyze the historical habitat conditions the functional classification of floodplain biotopes from Amoros et al. (1982; 1987) was used and the sub-classes for Eupotamon were adopted from Hohensinner et al. (2011). The classification states the intensity of hydrological connectivity of surface waters. With this method it is possible to analyze the different water body types in a qualitative way. Four types are differentiated:

1. Eupotamon consists of the lotic main channel arms and lotic side arms

- **a) Eupotamon A (EuA):** main channel (lotic), which carries most (>50%) of the discharge
- **b) Eupotamon B (EuB):** side arms (lotic), connected to the main channel at both ends at low flow

2. Parapotamon: former main and side arms more or less parallel and close to the main channel. Parapotamon are semi-stagnant water bodies and silted up at the upstream end, whereas the downstream end is still connected to the river

a) Parapotamon A (ParaA): dynamic backwaters (semi-lotic), blocked by gravel banks from the main channel on the upper end at low and mean flow but connected on both ends at summer mean water level

b) Parapotamon B (ParaB): less dynamic (semi-lentic) than ParaA and in contrast blocked upstream by vegetated sediment banks

3. Plesiopotamon (Plesio): isolated water bodies (lentic). Plesiopotamon are permanent or temporary standing water ecosystems with no permanent and direct connection to the river. They are astatic biotopes highly influenced by river discharge.

4. Paleopotamon: permanent or temporary standing water ecosystems with no permanent and direct connection to the river; rather stable biotopes, mildly influenced by river discharge.

For the analysis the differentiation of Paleopotamon was not possible, as closure dams did not disconnect them. The number of Plesiopotamon stretches was insufficient in the Faltbootführer (3rd map) due to the missing floodplain areas since it was a navigation map focusing on the main channel and a narrow section of the riverbank.

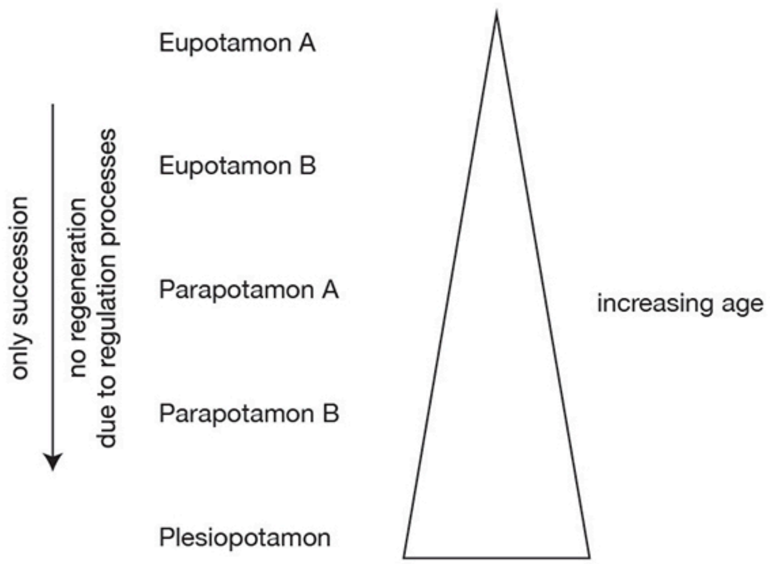


Figure 39: Scheme of supposed general succession in aquatic habitats with increasing age and growing decoupling of the floodplains due to the systematic river channelization, according to Hohensinner et al. (2011).

Floodplain habitats as they were characteristic for the basin stretches in the Austrian Danube were beneficial to the fish assemblages. For some Danube fish species they were even a necessity in their life cycle. With the river straightening also a change in the aquatic habitat composition took place, called morphological habitat succession. The succession progresses in a certain place from connected river arms and mainly main arms (EuA) and side arms (EuB) to disconnected (Plesio) or only on one side connected (ParaA, ParaB) water bodies that due to aggradation processes dried out (vegetated areas) and turned into hardwood riparian forests (Fig. 39). In an active riverscape, succession and regeneration (=rejuvenation) is in equilibrium. Older habitat types as the Plesiopotamon can turn into connected types again due to fluvial dynamics as erosion processes and floods. Before the start of the systematic river channelization (around 1870), regeneration could still take place in the Austrian Danube and therefore aggradation processes were not as severe as they are nowadays. The diversity in aquatic habitats proved important for the biocoenosis.

To analyze these changes, each closure dam was traced in the historical maps, whereby changes in the habitat type were recorded (e.g. former EuB turned into ParaB), in addition to the other parameters as described above (e.g. length). This resulted in a list of the different habitat types that exhibited succession, constancy or regeneration for each period of the compared time situations (1867 and 1892). The habitat turnover was determined by the share of the total measured lengths of the initial habitat in comparison to the developed habitat at the end of the analyzed time segment, e.g. the percentage share of 10 km side arms in 1867 to 4 km of side arms in 1892. Also, the change of lengths of the closure dams was measured (in km)(Fig.40).

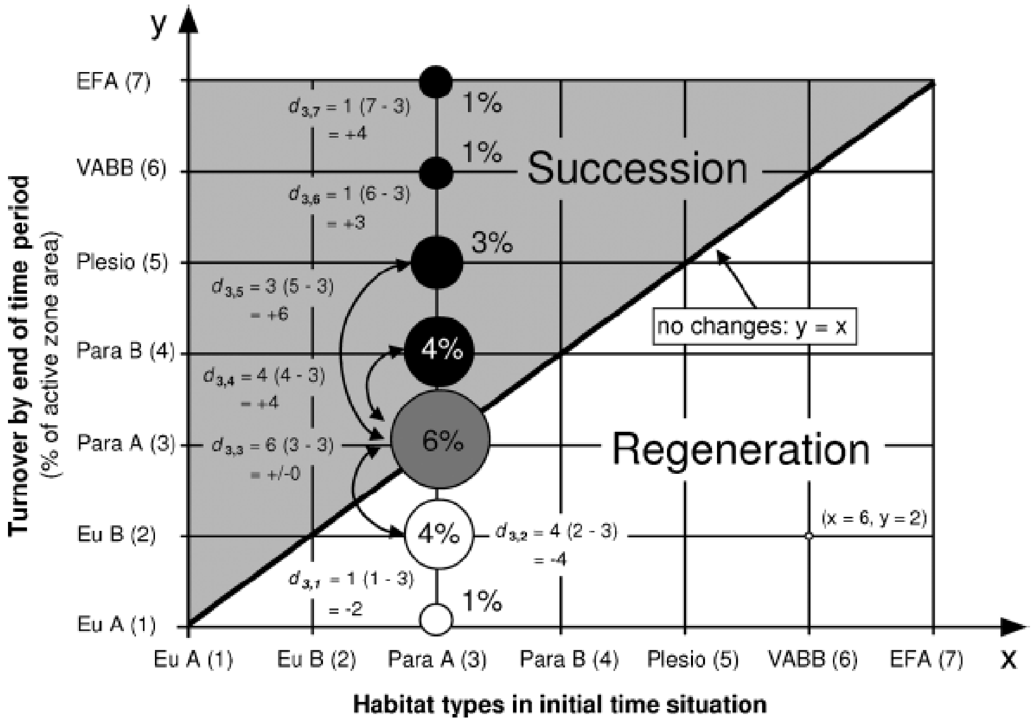


Figure 40: Schematic diagram of habitat turnover analysis: two-dimensional matrix of habitat types and calculation of habitat TI (not used in this thesis). Black spheres = habitat shares exhibiting succession, white spheres = regeneration, grey sphere = habitat shares that remain constant (for habitat type abbreviations see above) (Hohensinner et al., 2011).

3.5.3 Lateral connectivity width

Lateral connectivity can act as indicator for a dynamic riverscape (braiding river system). Side arms and backwaters are important migration corridors and provide diversity in habitat structures. For all branches diverting from the main channel the width of the connection was mapped. Side arms, backwaters and tributaries were included. The connection widths (in m) were summed up and put in relation to the length of the valley axis (Piller, 2012). The valley axis goes along the deepest point of the valley bottom. Figure 41 shows a detail from the Faltbootführer (1910) and the mapped connection widths in red. The higher the percentage of the lateral width, the better the river is connected with its surroundings.

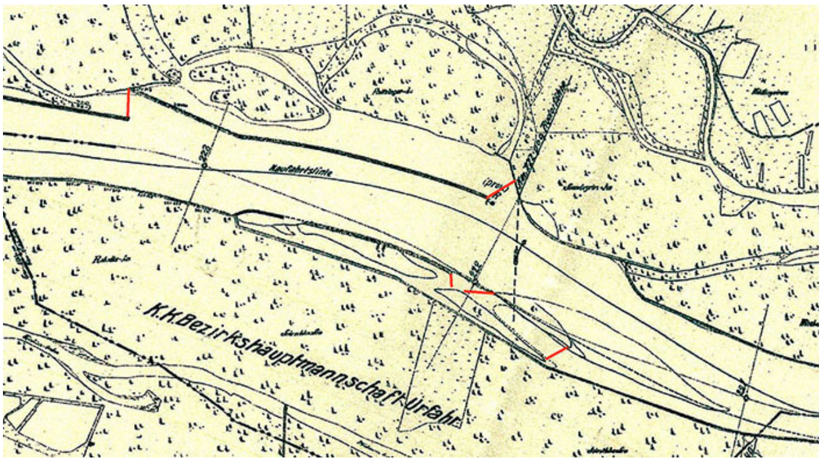


Figure 41: Connectivity lengths (in red) in the 3rd map (author/BEV).

3.7 Combining hydraulic constructions and lateral connectivity width

To estimate the channelization impact on the Danube in different time periods the comparison of the regulation intensity (the amount of hydraulic constructions) with the connection intensity (development of lateral connectivity width) can help to illustrate the changes and the progress of the river straightening. First the regulation intensity is calculated. All bank protections, closing dams and training walls in the main channel are summed (Regulation-Length). For this it is important that the regulations were mapped precisely to avoid overlapping. The sum of regulations along the main channel divided by the main channel length (length of both banks divided by 2) equals the regulation intensity (in %). The regulation intensity yields thus the percentage of regulated main channel banks; 100% regulation intensity signifies both banks of the main channel are continuously regulated. For calculating connection intensity all connection widths are summed up and measured in relation to the main channel length (in %). This is done for each time period to see trends in the development of the aquatic habitats.

3.8 Combination of the hydraulic structures and the fish market data

The analysis of the historical regulations in the Austrian Danube is further correlated with the changes in the fish composition, visible in the Viennese fish market data. First the parameters concerning the development of the regulations and the change in the aquatic habitats are examined. For this study only the changes in the basin stretches were considered, although the breakthrough stretches were mapped too. As a result, a list of all the hydraulic structures in the Austrian Danube, containing the year of construction, length and the spatial situation could be compiled.

After this analysis the fish composition as found in the Viennese fish market registers is done (see above). Finally the two sets of parameters are compared with a canonical correspondence analysis to see if there is a link between fish market data and the regulation activities. This can prove the hypothesis that fish market data can show changes in the fish species composition of the Danube.

Two parameters were chosen for the combined analysis. For the fish composition the annual amount in kg per potential Danube species is taken, for the regulation status the constructions in basins creating an average width smaller than 400 m and with a continuous length of more than 1 km (b-400, >1). In Microsoft EXCEL a dataset with both parameter groups is compiled. Consequently the data was divided into years (rows) and into the potential Danube fish species sold per year at the Viennese Fish Market (columns) as well as into the regulations constructed in that year in the basin stretches (columns). For the combined analysis, a canonical correspondence analysis (CCA) was performed in R, a free programming language software and an environment for statistical computing. The CCA is a multivariate analysis already used in similar studies to link biotic factors with abiotic ones (Pont et al., 2009). It shows the relationship between two sets of variables. The method detects pairs of linear combinations of each group of variables which are highly correlated. The CCA is a parsimonious way of dealing with multivariate data. CCA is “symmetric” in the sense that the sets X and Y have equivalent status, and the goal is to find orthogonal linear combinations of each having maximal (canonical) correlations. Pairs of linear combinations have to be found of each group of variables that are highly correlated. The results of the correspondence analysis are visualized as a graph of points (terBraak, 1986), which represent the rows, and columns of the table as relative values. Hence, the position of the points in the graph shows similarities between the rows, similarities between the columns

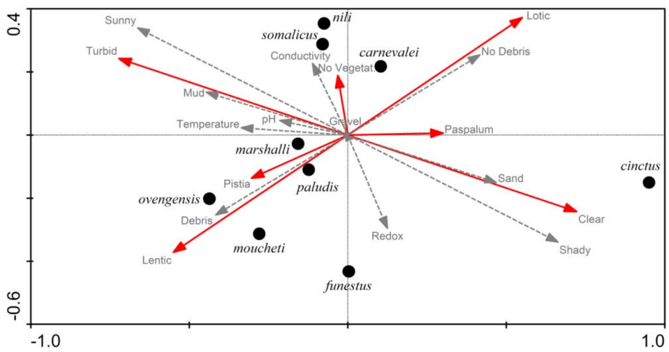
Chi-square (Observed value)	79.607
Chi-square (Critical value)	12.592
DF	6
p-value	< 0.0001
alpha	0.05

Eigenvalues and percentages of inertia:

	F1	F2
Eigenvalue	0.410	0.253
Inertia (%)	61.843	38.157
Cumulative %	61.843	100.000

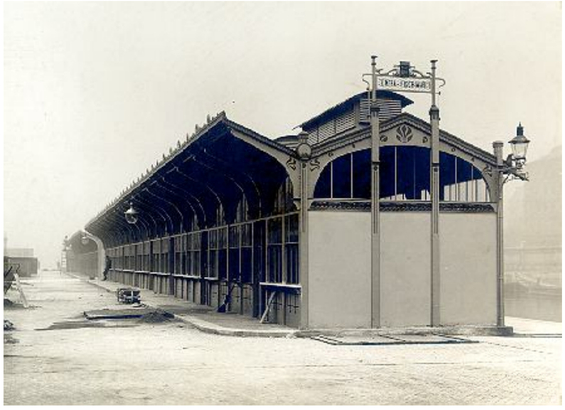
Contributions (rows):

	Weight (relative)	F1	F2
Brand A	0.333	0.626	0.015
Brand B	0.292	0.072	0.636
Brand C	0.208	0.058	0.169
Brand D	0.167	0.244	0.181



0.4
-0.6
-1.0
1.0
Sunny
Turbid
Mud
Temperature
pH
Gravel
Conductivity
No Vegetat
Lotic
No Debris
Paspalum
Sand
Clear
Shady
Redox
Debris
Lentic
Pistia
nili
somalicus
carnevalei
marshalli
paludis
ovengensis
moucheti
funestus
cinctus


LEOPOLDSTADT
II. B.
Trödel-Halle
Augarten Brk.
Rossauerkse.
Circus
Prater St.
Votivkirche
Börse
Jägerzeile
Issteg
Universität
Franzens-Brk.
Ferdinands-Brk.
Aspern-Brk.
Radetzky Brk.
Rathhaus
Weissgärber
K.k. Hoftheater
INNERE STADT
I. B.
Haupt-Post
Franz-Josef-Kaserne
Haupt Zollamt
Parlaments-H.
Volksgarten
S. Stefan
K.k. Hofburg
Museum
Stuben Brk.
Justiz Palais
Invalidenh.
Markt Halle
1
2
3
4
5



comparison with other kinds of meat (e.g. beef) showed that fish were already in the 17th century more expensive (Pribram et al., 1938). Throughout the years the difference grew bigger and fish were almost twice as expensive as beef (Table 8). In the beginning of the 20th century, the head of the Viennese fish market was convinced that with the import of cheaper marine species, fish as a food source could gain importance (Krisch, 1900).

Table 8: Prices of beef and fish in the period between 1610 and 1720, showing the price per pound in Kronen, at Stift Klosterneuburg (Pribram et al., 1938).

Year	Beef (kr./pound)	Carp (kr./pound)
1610	3.5	4
1662	3.25	6.90
1680	3	5.91
1703	4.75	10
1710	5	8.41
1720	5	11.27

4.1.1.1 Fish supply and fish trade

Until the end of the 19th century mainly freshwater fish were sold at the Viennese fish market. The fish mainly came from the Danube (e.g. “whitefish”), tributaries (mainly trouts) and fish farms (carps mostly from Bohemia). Around 1890 the only marine fish sold at the market were dried or salted stockfish, herring and flatfish (Krisch, 1900).

From 1850 the numbers of fish from the Middle Danube and the fishponds in Bohemia and Moravia began increasing at the fish market. A newly built railway line and steamboats supported the import of fish and accelerated the transport from further distances (Krisch, 1900). Marine fish species were sold only in the beginning of the 20th century as an alternative to the more expensive freshwater fish (e.g. salmonids). Farmed fish, mainly carp, were delivered in high quantities to the fish market with peaks during the feasting period and around festive days. The provenance and the status in which the fish were delivered (dead, alive, farmed) to the Viennese fish market were summarized for assorted freshwater species in Krisch (1900) (see Table 9).

Table 9: Provenance of the freshwater fish delivered to the Viennese fish market according to the territorial borders of 1900 (transcribed after Krisch, 1900).

Fish species	Territory	Provenance
eel	Bohemia and Hungary	Moldau, farmed fish
grayling	Upper Austria, Styria	delivered dead
barbel	Lower Austria	Danube
perch	Lower- and Upper Austria	Danube, farmed fish
bream	Lower- and Upper Austria	Danube, Attersee
	Tyrol	Lake Constance
	Hungary	Lake Balaton
trout	Lower- and Upper Austria	Danube
	Bohemia	
beluga sturgeon	Hungary	mainly Lower Danube
pike	Lower- and Upper Austria	Danube
	Hungary	Lower Danube
	Styria	Drava
	Croatia	Save
	Bohemia & Moravia	farmed fish
Danube salmon	Lower- and Upper Austria	Danube & tributaries
	Styria	
	Hungary	Danube & tributaries
carp	Bohemia & Moravia	farmed fish
	Styria	farmed fish
	Galicia	farmed fish
	Hungary	Lower Danube
	Romania	Lower Danube
salmon	Bohemia	Moldau, Elbe
	Germany	Rhein
	Holland	
	Russia	Vistula
	America	
salmon trout	Upper Austria	Danube, mainly lakes

Fish species	Territory	Provenance
char	Upper Austria, Styria	lakes
wels	Hungary	Danube, Tisza, Lake Balaton
	Croatia, Slovenia	Drava, Save
	Carinthia	lakes
	Bohemia	farmed fish
	Moravia	March,farmed fish
	Romania	Danube
pikeperch	Lower- and Upper Austria	Danube
	Hungary	Danube, Tisza, tributaries
	Croatia	Save
	Moravia	March, farmed fish
	Bohemia	farmed fish
	Germany	Curonian Lagoon (Frisches-, Kurisches Haff)
	Russia	Astrachan, Rostow
	Romania	Braila
tench	Upper Austria	Danube
	Hungary	Danube
	Bohemia	farmed fish
sterlet	Hungary	Danube, Tisza
	Croatia	Save
	Russia	Volga
	Romania	Danube
„whitefish“	Lower- and Upper Austria	Danube, tributaries
	Hungary	Tisza, tributaries

As Table 9 shows, at the turn of the 20th century the potential Danube fish species came from the whole Austrian Danube. If the fish were not from the Danube, or from ponds and tributaries in the Austrian Monarchy the fish stemmed from the Adriatic Sea or the North Sea. As of 1899, the German steam-fishery society “Nordsee” delivered fish from the North

Sea to Vienna (Krisch, 1900). The North Sea was the preferred source for marine fish because of its species richness and the suitability for deep-sea fishing. The geographically closer Adriatic Sea could not fulfill these requirements and the transport costs to Vienna were very high which made the trade unprofitable (Krisch, 1900).

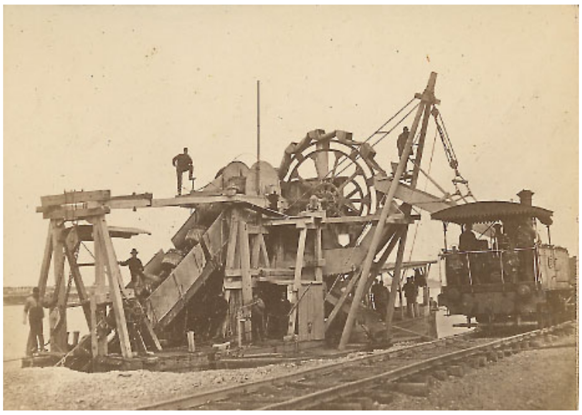
4.2 Development of hydraulic structures along the Austrian Danube

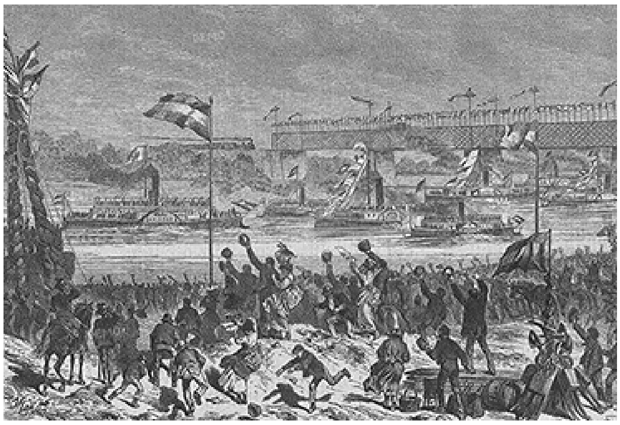
Three periods could be distinguished to describe the development of hydraulic structures along the Austrian Danube as indicated in the methods. These periods were also used in the contemporary literature of the 19th and 20th century and one period was added describing the hydraulic structures prior to 1850 (OÖ Statthalterei, 1909; Donauregulierungs-Kommission, 1898; Weber, 1897; Baumgartner, 1862).

The contemporary literature focused on the hydraulic structures built in Vienna and its surroundings (Lower Austria) (Donauregulierungs-Kommission, 1886; 1898; 1909; 1897). Many of the engineering works accomplished in Vienna were representative for other sections of the Austrian Danube except for the rather early erection of flood protection dykes in Vienna.

4.2.1 Hydraulic constructions prior to 1850

The conditions prior to 1850 will be described mainly for the section in and around Vienna. It can be considered as representative of the hydromorphological conditions in basin sections. Further, the Viennese Danube was back then apart from the Machland and the breakthrough section of Struden in the focus of the engineers. Under the climatic and hydrological conditions of modern times, in its pre-channelization state, the Viennese Danube section was a gravel-dominated, laterally active anabranching river associated with a medium-energy, primarily non cohesive floodplain (according to the river/floodplain classification schemes of Nanson & Knighton, 1996). Anabranching rivers have a complex channel network with numerous vegetated islands and gravel bars (Fig. 49). On the Viennese Danube, the highly variable alpine flow regime with high loads of coarse bed material was one main underlying factor. Prior to channelization, 500 000 m^3 gravel and 5.6 million tons of suspended load were transported annually downstream (Penck, 1891; Schmautz et al., 2000; in Hohensinner et al., 2013). Summer and autumn floods after heavy rainfalls in the upper catchment, melted snow floods in spring and in winter as well as ice jam floods caused the major changes in the channel system of the Danube (Hohensinner et al., 2013). High bed shear stress incised new channels into the floodplain (Fig. 49) (Richards et al. 1993). At side arms, large woody debris had similar impacts. Flows between mean water and bank full water level (approx. 1-year flood) contributed to lateral channel migration, which could





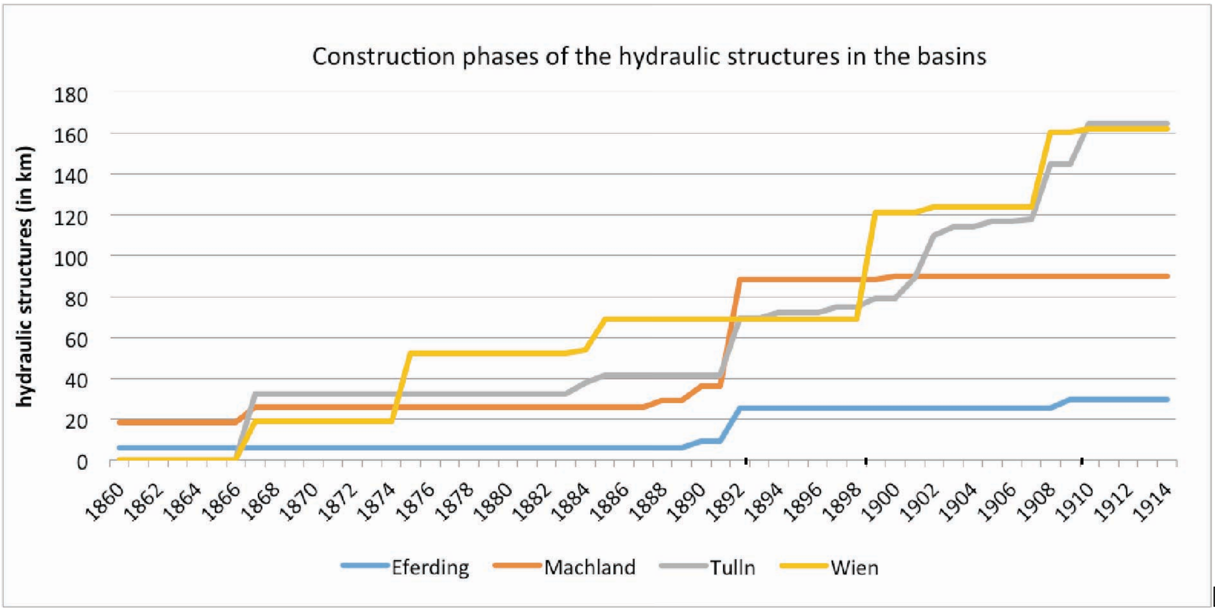
Achieved goals of the mean water regulation

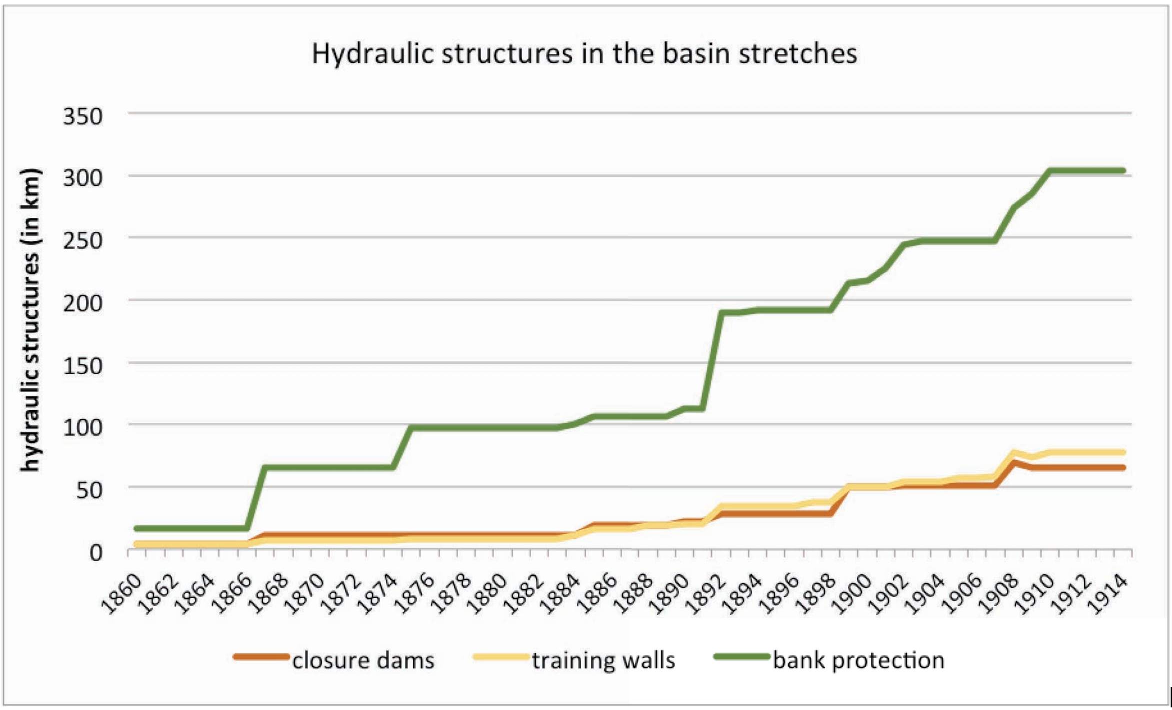
side arms due to the decoupling from the main channel, also led to a favoring of this development (Donauregulierungs-Kommission, 1909). Ice jams were reduced due to the river channelization. The formation of ice was almost impossible after the regulation because of the higher depths and flow velocities. In addition, an ice cover could develop only in a single stream and not in several. Before, the braiding river system with many shallow arms fostered the formation of ice on many places. In addition bank protections favored the ice transport further downstream due to its even surface.

4.2.4 Hydraulic constructions between 1893 and 1910

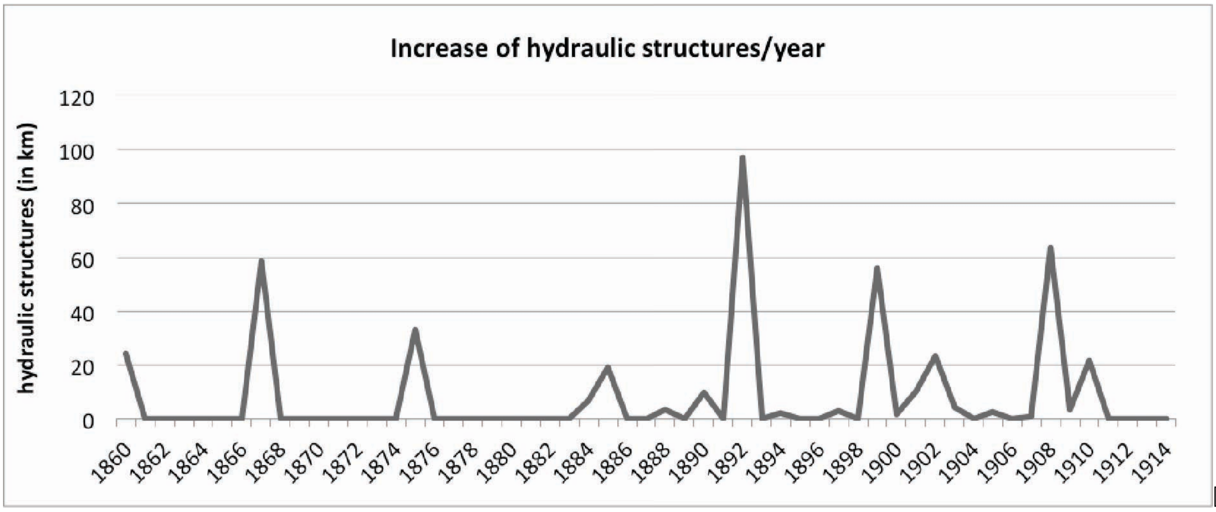
In the period from 1893 to 1910, the systematic river channelization (river straightening) was finalized in the Austrian Danube and the implementation of the low flow regulation started in Vienna. The measures were supposed to guarantee save navigation also during low discharges. After the completion of the works in Vienna, the surrounding Danube stretches were regulated (Donauregulierungs-Kommission, 1897). Excess widths were abolished, using training walls to guarantee a minimum depth for navigation (Waldvogel, 1910).

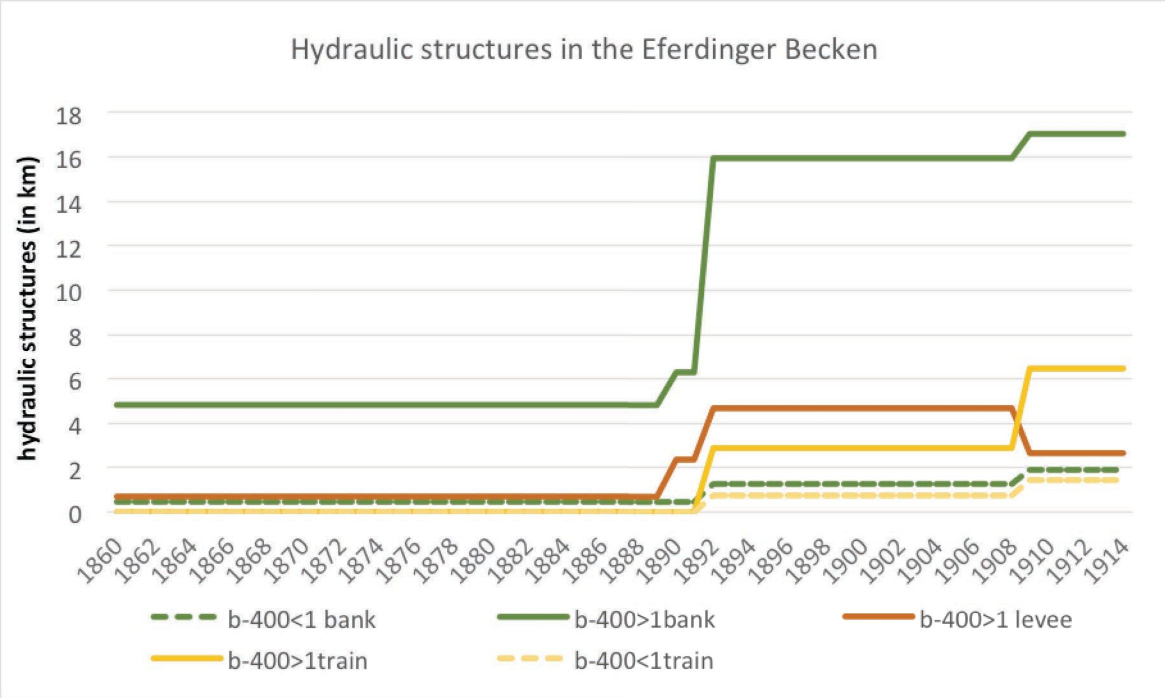
After the completion of the Viennese Great Danube Regulation, the new main channel could not guarantee a sufficient river width for navigation (Thiel, 1904). The shipping route had to constantly adapt to newly formed gravel banks and shallow stretches, especially during low flow conditions (Donauregulierungs-Kommission, 1909). Local excavations were supposed to remove these obstacles, but only temporary improvements could be achieved. In 1895 Ritter von Weber started the low flow regulation in Vienna. Spur dykes were installed above the low water table on the left riverbank to concentrate the discharge in a narrower and deeper channel. At the end of the spur dykes, training walls were built parallel to the riverbank at the same height as the spur dykes. The hydraulic structures should guarantee that the water remained between the training walls and the opposite riverbank during low flow conditions. Starting in 1895 the constructions were almost completed after one year in the Viennese part. The hydraulic works were extended up and downstream, but the construction technique changed, since the training walls were now omitted and the spur dikes were erected in closer proximity to each other (Donauregulierungs-Kommission, 1909). Similar work was done in the other stretches of the Austrian Danube.


Construction phases of the hydraulic structures in the basins
hydraulic structures (in km)
0
20
40
60
80
100
120
140
160
180
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
Eferding
Machland
Tulln
Wien

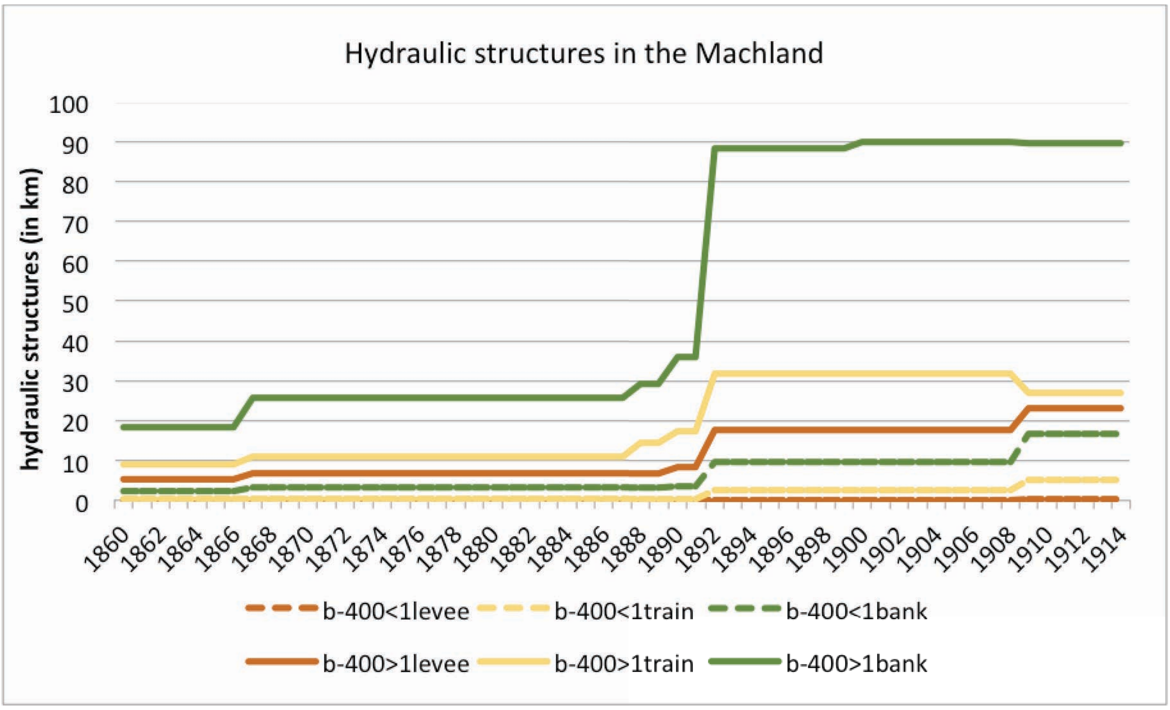


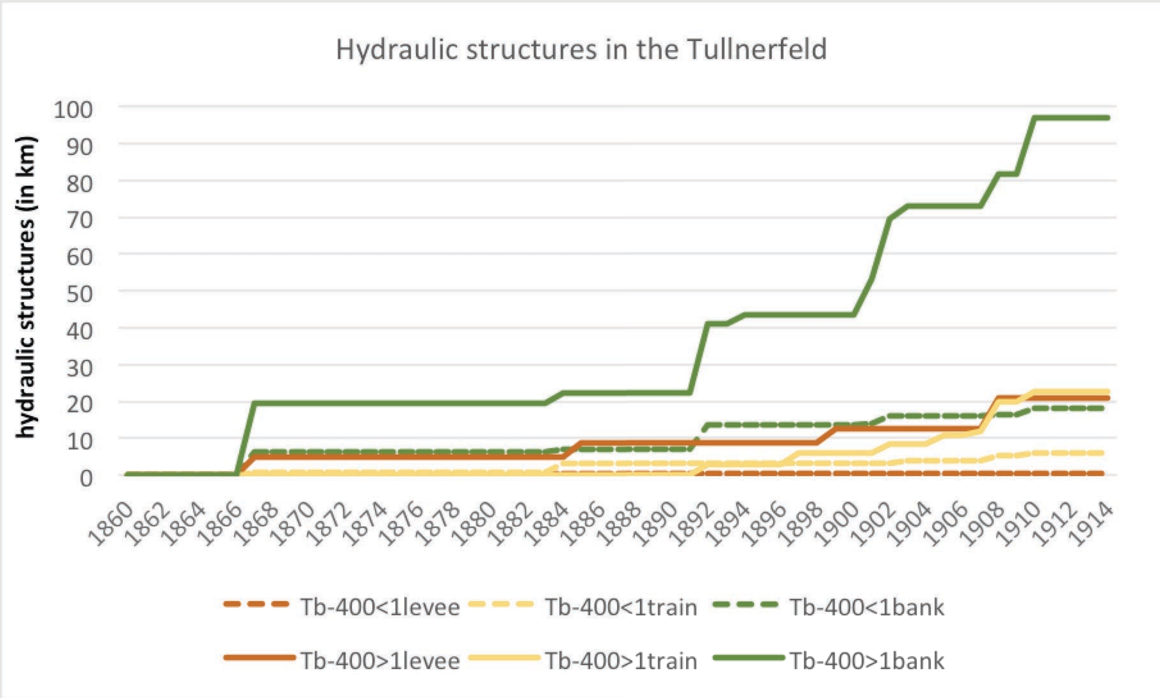
Hydraulic structures in the basin stretches
hydraulic structures (in km)
350
300
250
200
150
100
50
0
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
closure dams
training walls
bank protection


Increase of hydraulic structures/year
hydraulic structures (in km)
120
100
80
60
40
20
0
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914

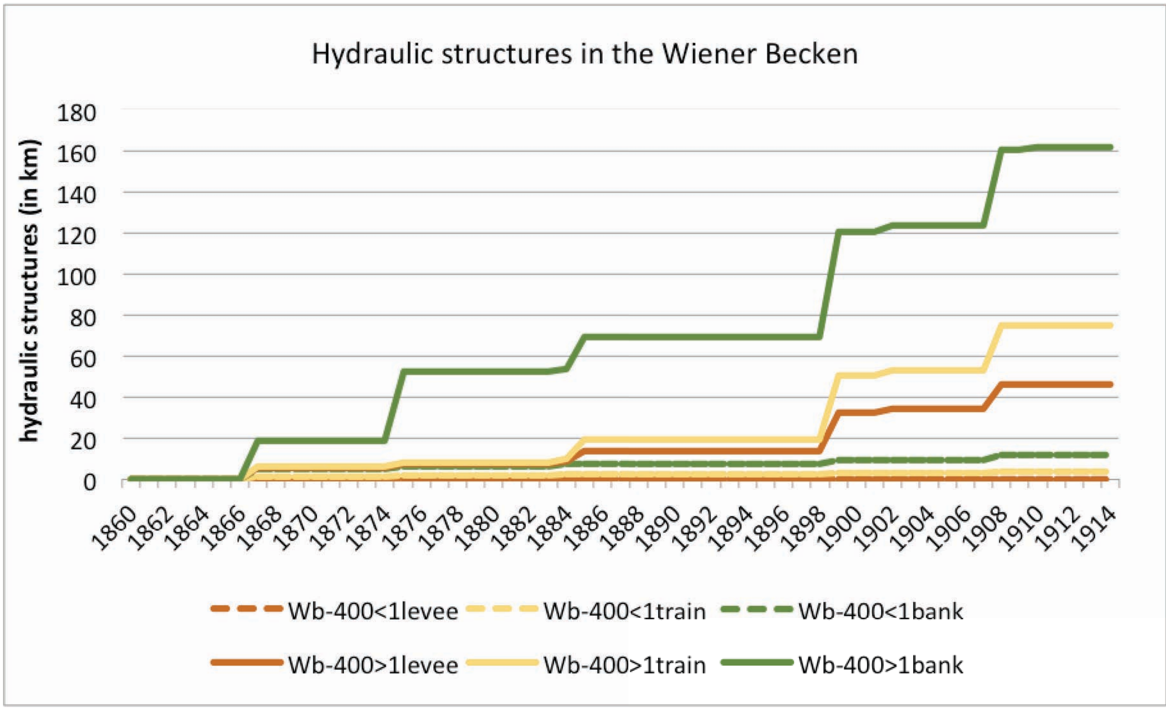

Hydraulic structures in the Eferdinger Becken
hydraulic structures (in km)
18
16
14
12
10
8
6
4
2
0
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
b-400<1 bank
b-400>1bank
b-400>1 levee
b-400>1train
b-400<1train


Lindham
Pösting
Ob. Ottensheim
Obstgarten
Neuwiesen
Waidau
Haber-Au
Au Wiesen
Wilhering
D O N A U


Hydraulic structures in the Machland
hydraulic structures (in km)
100
90
80
70
60
50
40
30
20
10
0
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
b-400<1levee
b-400<1train
b-400<1bank
b-400>1levee
b-400>1train
b-400>1bank


Hydraulic structures in the Tullnerfeld
hydraulic structures (in km)
100
90
80
70
60
50
40
30
20
10
0
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
Tb-400<1levee
Tb-400<1train
Tb-400<1bank
Tb-400>1levee
Tb-400>1train
Tb-400>1bank

TULLN



Hydraulic structures in the Wiener Becken
hydraulic structures (in km)
0
20
40
60
80
100
120
140
160
180
1860
1862
1864
1866
1868
1870
1872
1874
1876
1878
1880
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
Wb-400<1levee
Wb-400<1train
Wb-400<1bank
Wb-400>1levee
Wb-400>1train
Wb-400>1bank

width less than 400 m extended in 1867 over 19 km. In 1875 already 52 km were effected and after 1910 160 km of regulations existed in the Wiener Becken. This high number might have been due to the low flow regulation, i.e. the installation of groynes to provide a sufficient water depth for navigation and the flood protection dams (Hubertusdamm). As a result, the river width was adjusted to less than 300 m especially in the stretch around Vienna. After the systematic river regulation the Wiener Becken was 55 km long, considering both sides of the banks it was 110 km.

4.3.2 Aquatic habitat change

Some of the hydraulic structures, namely the closure dams, disconnected water bodies and severely altered aquatic habitats and migration routes of fish. Due to channelization the formerly dominating permanently connected side arms (Eupotamon B) were almost completely lost (Fig. 61) by the beginning of the 20th century.

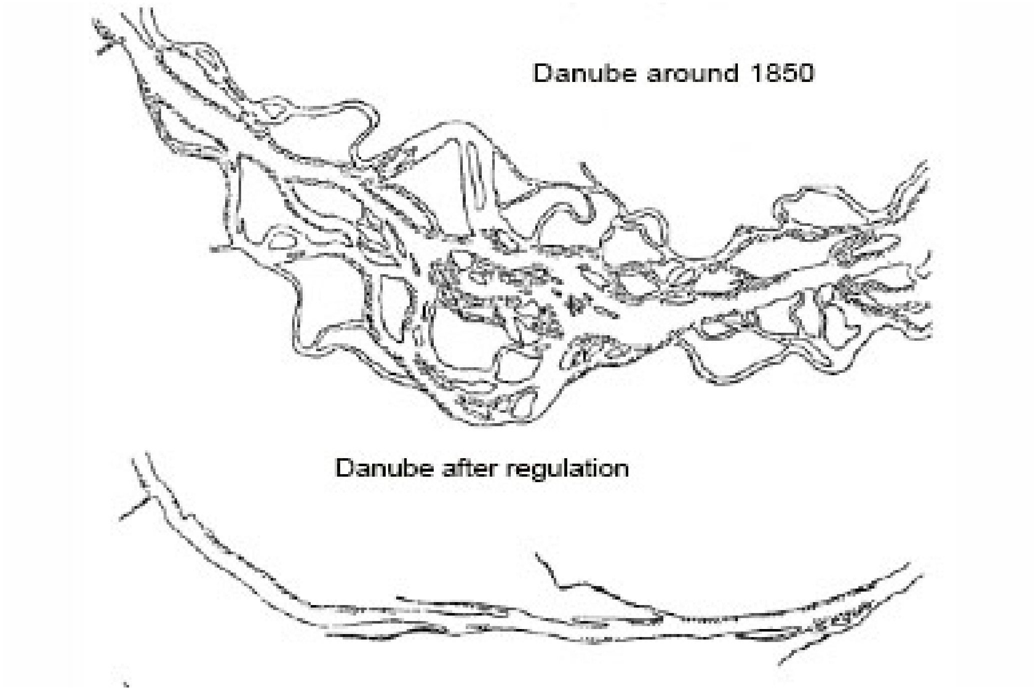
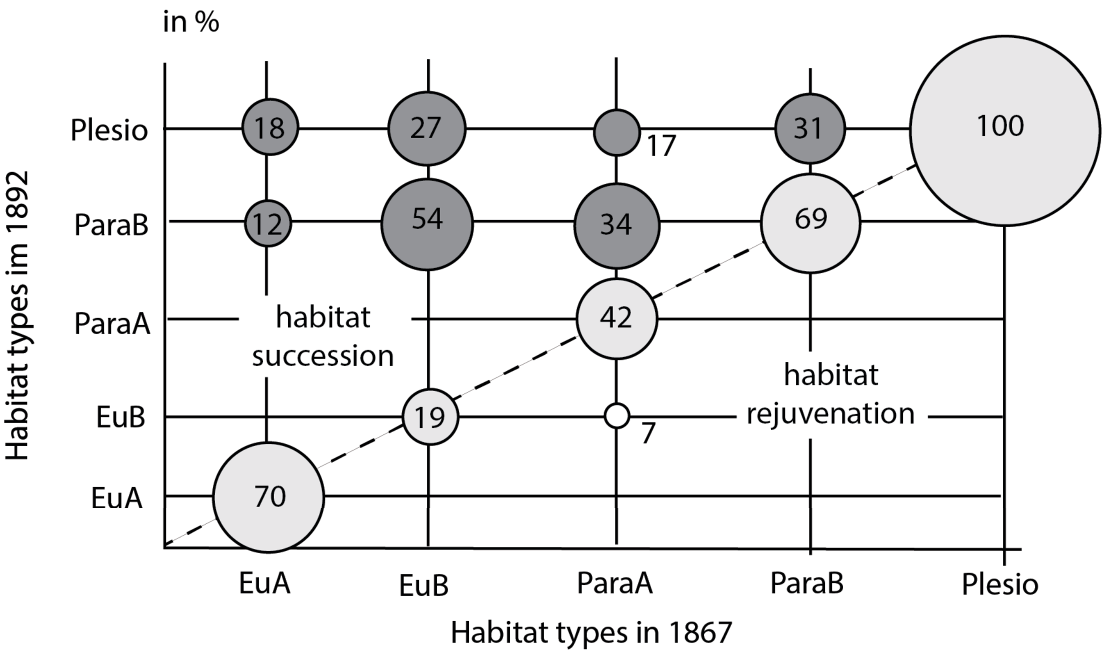


Figure 61: Morphological changes in the Danube due to the regulations, Danube around 1850 as nested system and after regulation as a curved line in the area between Aschach and Wilhering in Upper Austria (Zauner, 1991).

In unchannelized rivers fluvial dynamics results in habitat succession and regeneration (=rejuvenation) processes which were more or less in an equilibrium (Hohensinner et al., 2011). Thus the proportion of Eupotamon, Parapotamon and Plesio-/Paleopotamon was always similar. The hydraulic structures stopped rejuventation (=regeneration) processes. Figure 62 shows the changes in habitat that happened between 1867 and 1892. The main


in %
Plesio
ParaB
ParaA
EuB
EuA
Habitat types im 1892
18
27
17
31
100
12
54
34
69
42
habitat
succession
19
7
habitat
rejuvenation
70
EuA
EuB
ParaA
ParaB
Plesio
Habitat types in 1867

2. Side arms connected on both sides turned into disconnected water bodies (EuB to Plesio).
3. Backwaters connected on their downstream end and disconnected upstream by a gravel bar transformed into a backwater disconnected upstream by closure dams or terrestrial areas (etc.) (ParaA to ParaB).
4. Backwaters connected on their downstream end and disconnected upstream by a gravel bar transformed into a stagnant water body with no permanent connection to the river (ParaA to Plesio).
5. Backwaters connected on the downstream end and disconnected upstream turned into a stagnant water body with no permanent connection to the river (ParaB to Plesio).

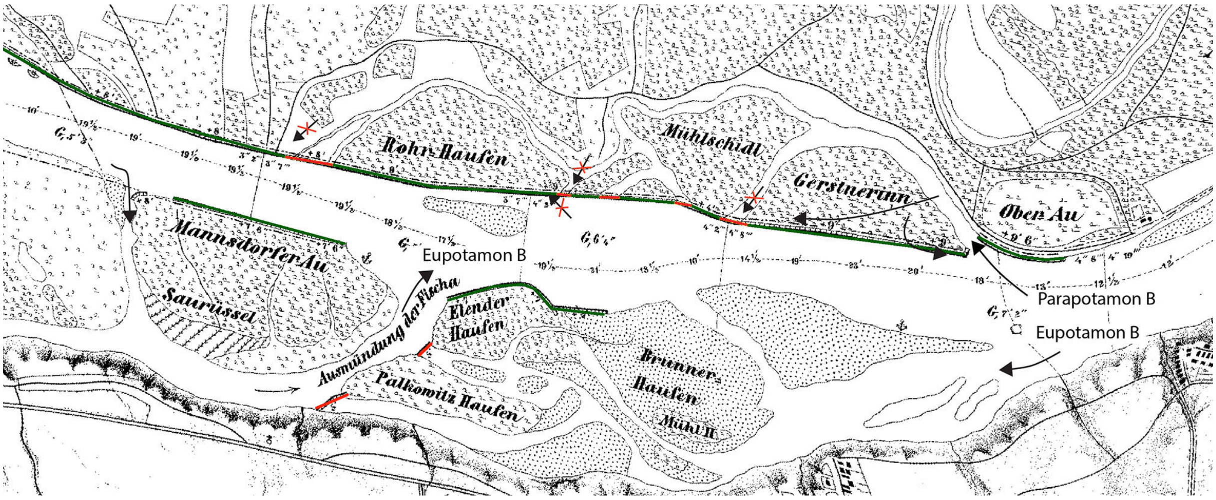


Figure 63: The change of the aquatic habitats due to hydraulic structures (green=bank protection, red= closure dam) around 1867 (Pasetti map). The arrows show the accessibility of the side arms and backwaters. Red-crossed arrows indicate the inaccessibility due to hydraulic structures (author/BEV).

Five succession types were also found in the second observed time period from 1875 to 1892 (3rd Military Survey) (Fig. 64):

1. Main arm turned into a standing water ecosystem with no permanent connection to the river (EuA to Plesio) (e.g. the old main arm of the Danube in Vienna, the "Kaiserwasser", after the excavation of the new main channel).
2. Main arm turned into a sidearm connected on both ends (EuA to EuB)
3. Side arms connected on both ends turned into disconnected water bodies (EuB to Plesio)

4. Side arms connected on both ends turned into side arms only connected on the downstream end (EuB to ParaB)
5. Side arms connected on both ends transformed into backwaters connected downstream and blocked upstream by a gravel bar (EuB to ParaA)

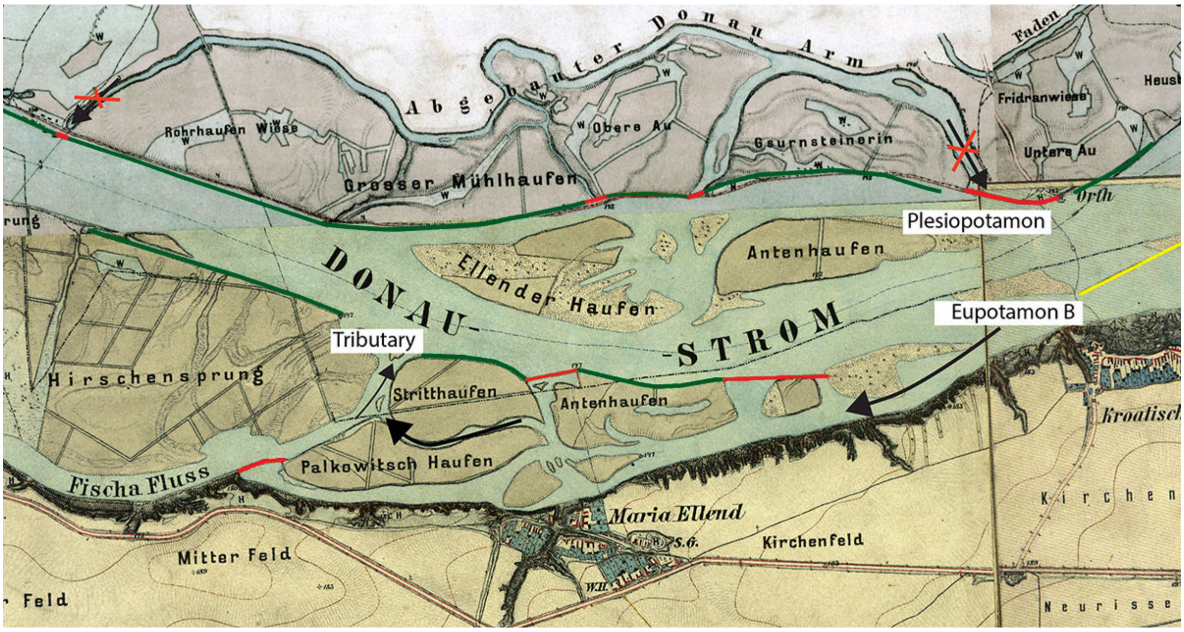


Figure 64: The change of the aquatic habitats due to hydraulic structures (green=bank protection, red= closure dam) around 1892 (3rd Military Survey). The arrows show the accessibility of the side arms and backwaters. Red-crossed arrows indicate the inaccessibility due to hydraulic structures (author/BEV).

In the third period from 1893 to 1910 (Faltbootführer) three types of succession were found (Fig. 65):

1. Side arms connected on both ends turned into side arms only connected on the downstream end (EuB to ParaB)
2. Side arms connected on both sides turned into disconnected water bodies (EuB to Plesio)
3. The main arm turned into a stagnant water body with no permanent connection to the river (EuA to Plesio)

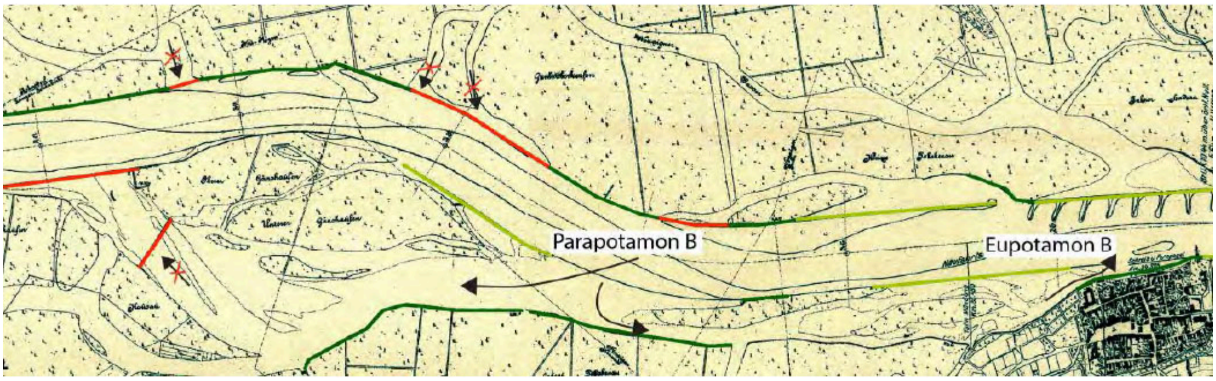


Figure 65: The change of the aquatic habitats due to hydraulic structures (green=bank protection, red= closure dam) around 1910 (Faltbootführer). The arrows show the accessibility of the side arms and backwaters. Red-crossed arrows indicate the inaccessibility due to hydraulic structures (author/BEV).

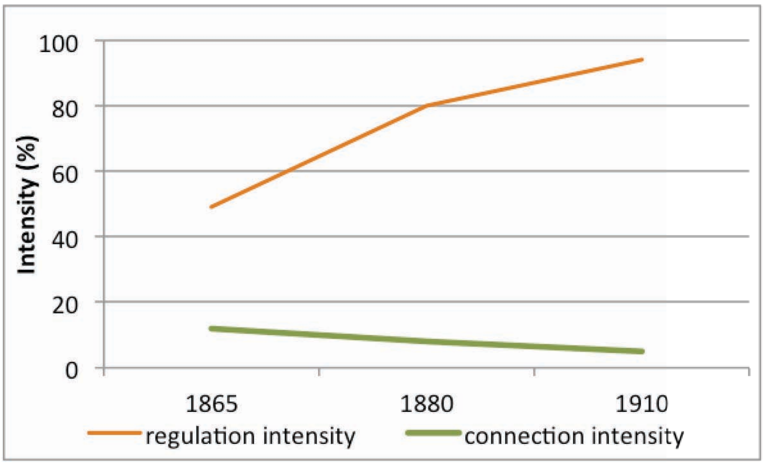
4.3.3 Combining hydraulic structures and lateral connectivity width

To compare the progressing regulation with the changes in the aquatic habitats in the Austrian Danube the regulation intensity and the connection intensity were taken as indicators. In Table 10 the connection of side arms and backwaters to the main channel is shown in length and in percent. Around 1867 still 82 km connection widths existed. Around 1910 only 28 km were still connected. In 1892 as intermediate state 47 km of connection widths were measured.

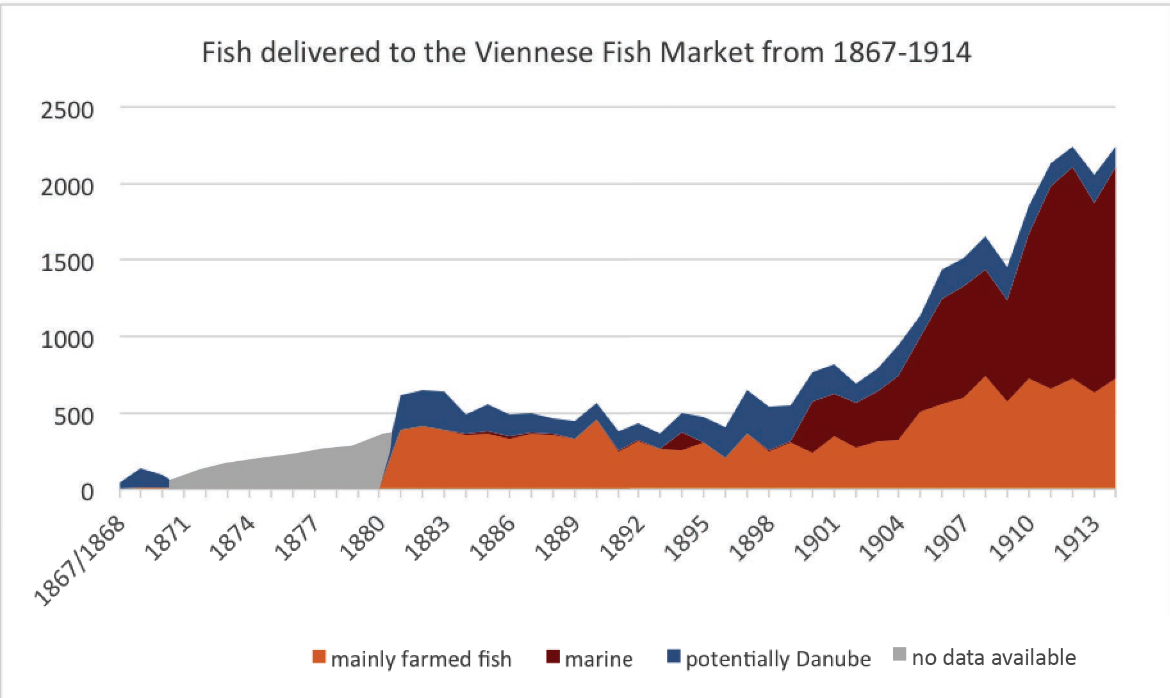
Table 10: Regulation intensity and the change of the connection widths during the three studied time periods: 1867, 1892 and 1910.

	Main channel length (km)	Regulation-Length (km)	Regulation-Intensity (%)	Connection-widths (km)	Connection-Intensity main channel (%)
1867	694	343	49	82	12
1892	583	468	80	47	8
1910	568	533	94	28	5

Figure 66 shows the relationship between the increasing regulation intensity and the loss of connectivity widths to the main channel. As a consequence important aquatic habitats were lost. In the Austrian Danube the connection intensity was 12 percent in 1865. In 1910 only 5 percent were left. The regulation intensity developed in the opposite direction. 49 percent of the Danube were regulated in 1865 and 94% in 1910 when computing the length of hydraulic structures in relation to the valley axis.


100
80
60
40
20
0
Intensity (%)
1865
1880
1910
regulation intensity
connection intensity

[illegible]



Fish delivered to the Viennese Fish Market from 1867-1914
2500
2000
1500
1000
500
0
1867/1868
1871
1874
1877
1880
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1913
mainly farmed fish
marine
potentially Danube
no data available

about 1 million people lived in the city, in 1914 more than 2 million. Especially the imported marine species offered the opportunity of better fish supply. Farmed fish formed the majority of fish in 1881 with 62% of the total amount. 37% were potential Danube fish and only 1% were marine species. The proportion changed over the years. In 1890 marine species were still rare on the market (2%). The number of potential Danube fish had declined (22%) and that of farmed fish increased (76%). From 1899 on, marine species were delivered in large amounts. In 1901 their share amounted to 42%, 23% were Danube fish and 35% farmed fish. In the beginning of the 20th century, the proportion of Danube fish species further decreased in trend, although one can observe big fluctuations. In 1914 only 6% of the total delivery came from the Austrian Danube while 62% were marine species (Table 11).

Table 11: Share of different provenances in the total supply of fish delivered to the Viennese fish market (in %).

Provenance	Percentage of total supply (in %)
Lake fish	0.6
Tributaries	0.5
Farmed fish	44.2
Marine	35.2
Non-Danube	0.3
Potentially Hungarian Danube	0.1
Potentially Austrian Danube (Incl. pikeperch and wels)	18.7 (7.4 and 0.5)

Table 12: Fish delivery to the Viennese fish market, assorted years and species (pot. Danube = potential Danube fish, farmed fish, marine fish and the overall delivery (in tons).

Years	pot. Danube (t)	farmed fish (t)	marine fish (t)	overall (t)
1881	223	384	4.4	632
1885	176	366	12	610
1890	128	454	2.5	594
1901	190	348	276	816
1908	222	740	696	1700
1914	129	720	1386	2239

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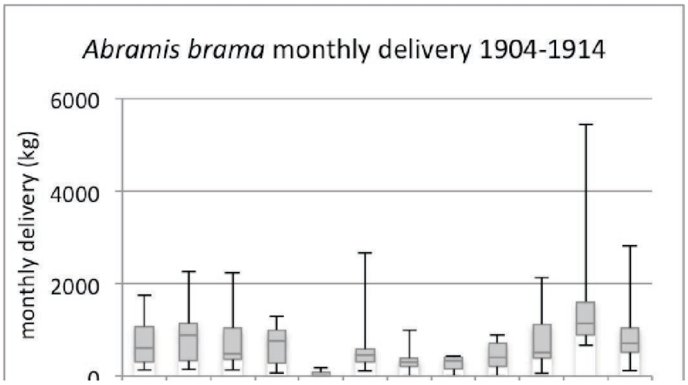
wqwqJ Unf Lsvmsf e aLnf Ls f S n n snd

ti d BhKäKkr Dti o kdDt Bh D KpoWWkOD n Dti K KpoWDkdK kpDDti WkD dDB d p i räKt KWi'Uai KS kOJ P kr Dti WkD dDB d p i KWi'Uai KKprräUaidD o kdDt Bh D - iO m ä B B Dk iA ädi Dti äO hi Bami Oh Dk Dti o D üi Dkmi OD ti hi D n Ut d siK npOäds D k närri OdDWi'OknKS

Bo kKD dk Od K- iO KkBn äd Dti UBkKin Ki K kd rOko Dti J[KD] kr h Dk Dti idn kr h



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u : : l Fulg 2 ve o FvT2 5b" E(5b5E4 Tl l T: 9
f 4

1 äs S6x5S tä K KidUi o i K Kk Bn Dti K KpoWDkd DtD Dti Od äK WkD dDB d p i KWi'Uai K BDtkpst Kkoi - iO Gdimi ODti B KKGDO in o h i rOko pdsD h kO üi kdKD Ui 1Ki i kmi dn OKUtG zPP5S ti d BhKäK- K dkDWkKKä B rkODti äOKDDo i KWd rOko xxJ Dk xzT iUp Ki o kdDt Bh D - iO m ä B B kdBh D O xzzS

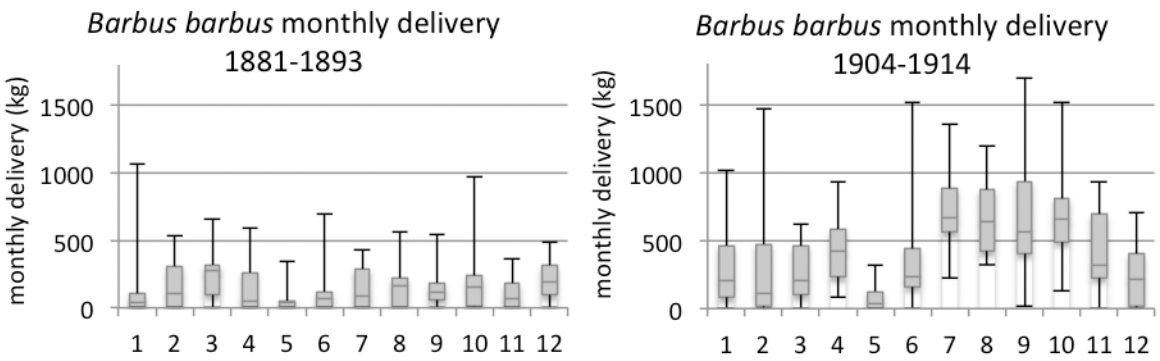


Figure 69: Monthly delivery (in kg) of barbel to the Viennese fish market from 1881 to 1893 (left) and from 1904 to 1914 (right). Closed season from the middle of May to the middle of June.

The barbel had its closed season from the middle of May to the middle of June. The delivery in these months was lower than in the other months (Fig. 69). The closed season of barbel was strictly followed due to the fact that the fry of the barbel is inedible (Hauer, 2011).

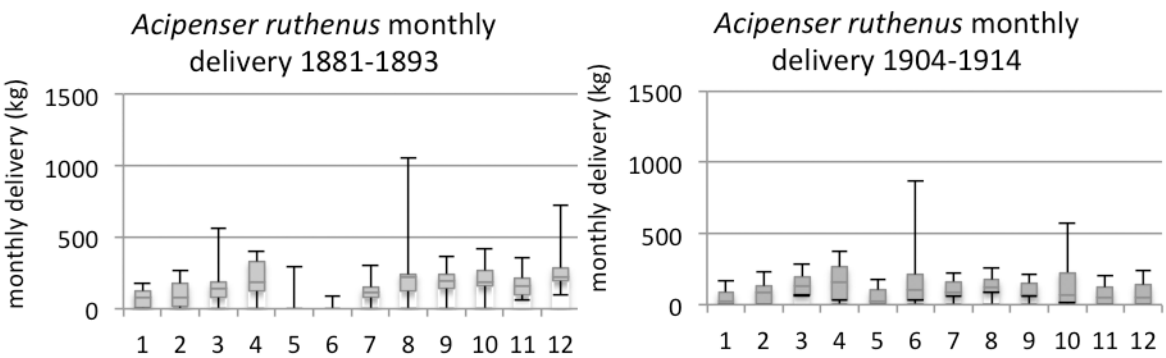
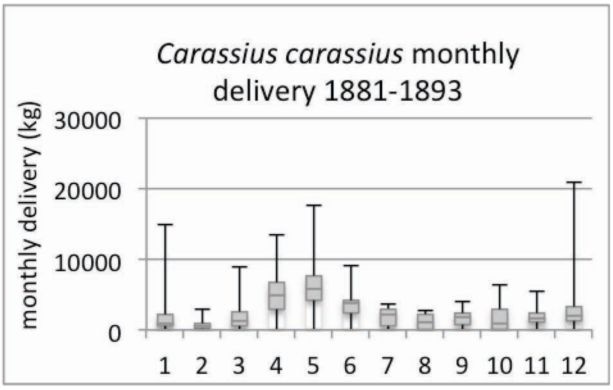


Figure 70: Monthly delivery (in kg) of sterlet to the Viennese fish market from 1881 to 1893 (left) and from 1904 to 1914 (right). Closed season from May to June.

In the period between 1881 and 1893, no sterlet were delivered to the market during the closed season. It can be assumed that during this time the sterlet stemmed mainly from the Austrian Danube (Fig. 70). In the second period from 1904 to 1914, sterlet were also delivered during its closed season, so probably the fish had been imported from Bohemia, Hungary, Croatia and Romania (see above and Krisch, 1900).



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	J	K	PO	PP	PJ
P: OK		88P			
P: Oz		9PP			
P: O2	8x8P				
P: O:				JxP	
P: PJ	EPP			TPP	
P: PT					zPP
P: Pw	EPP		J8PP		

ti OpUd UO W - K hi Bmi On Dt Okpstkp DDti - tkB hi O G - äDt o A äo po äd WO2B n h äd Dti Wi Okn rOko JxxJ Dk JxzT 1 äs 9J 5S ti OpUd UO W tn dk UkKin Ki K kd n Dti O rk O - K hi Bmi On Dk Dti o O üi D Dt Okpstkp DDti - tkB hi O S k ODti Ki Ukdn Wi Okn rOko zPö Dk zJö äd Kprr äUi dD hO rk O kAW k D - i O m ä B B 1 B T5S ti kpdDK kr OpUd OW tn Dti d hOk W Wi n Kt O Wh S imi OB AW D äkdK Di WkKKä B S di o ästD i ni Ui di kr Dti äDt äDD d n DtpK KDOkds ni UO K i kr Dti äD WkWp D äkdK d kDti OO K kd o ästD i Ut d sin äKtäds WDO D Ui K kO K k WOri O dUi K kr UkdKpo i OKS

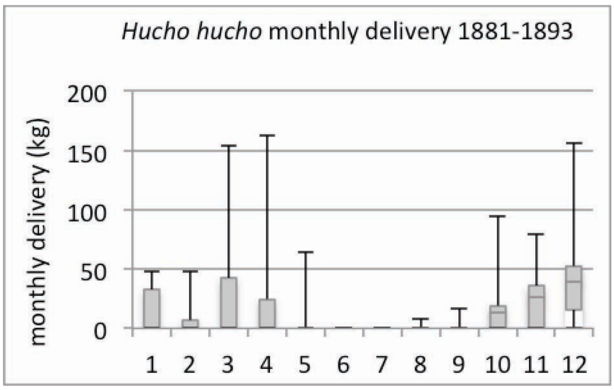

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Table 14: Monthly delivery (in kg) of Danube salmon from 190 to 1914.

	5	10
1906	10	12
1907	0	0
1908	0	0
1909	0	0

The Danube salmon was mainly delivered in late autumn and winter, but also during the closed season in Lower Austria from the middle of March until the end of April (Fig. 72). It can be assumed that the Danube salmon were delivered from other places (e.g. Hungary and Styria, see above and Krisch, 1900). For the second period, too little data were available to generate a boxplot (Table 14).

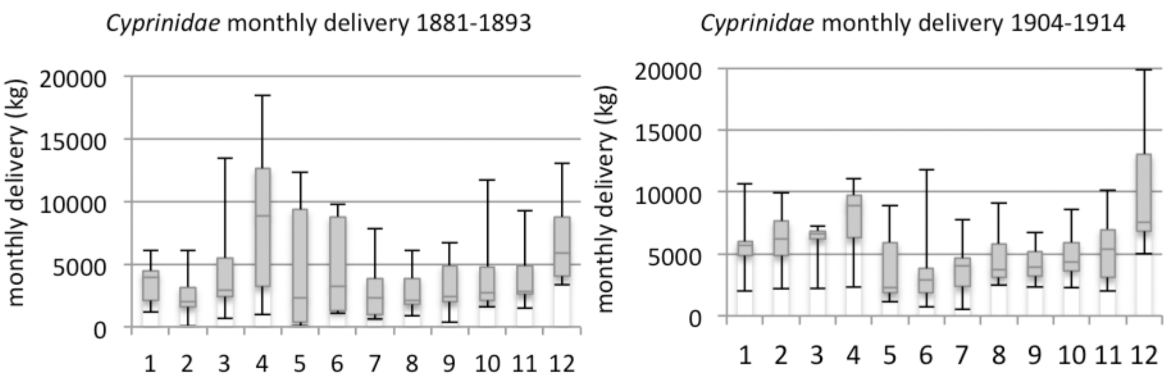

Figure 73: Monthly delivery (in kg) of "whitefish" to the Viennese fish market from 1881 to 1893 (left) and from 1904 to 1914 (right). No closed season (only for assorted species, e.g. bleak, nase, ide).

The "whitefish" were delivered throughout the whole year. In the period from 1881 to 1893 most "whitefish" were sold around April (for Easter) and in December (for Christmas) (Fig. 73). As reported in Krisch (1900) "whitefish" were used as substitute for carp on festive days, for the poorer population. In the second period a similar pattern was visible.

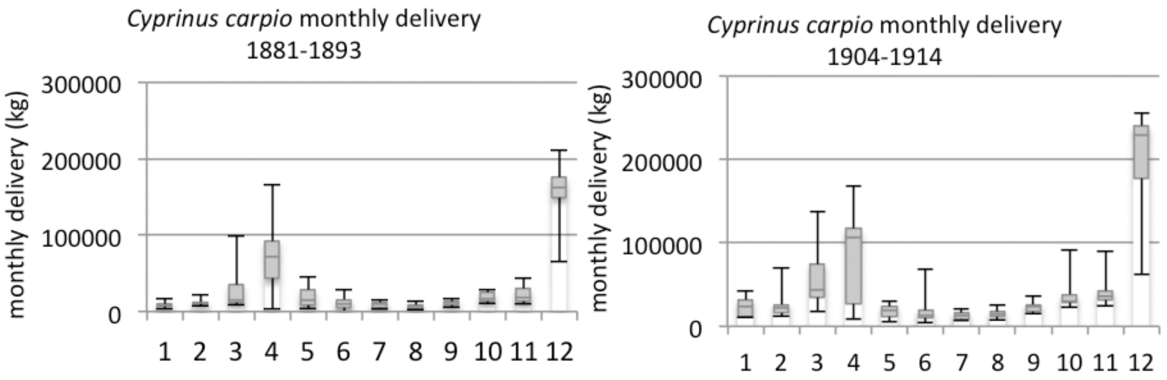

Figure 74: Monthly delivery (in kg) of carp to the Viennese fish market from 1881 to 1893 (left) and from 1904 to 1914 (right). Closed season in May.

The common carp were mainly farmed fish (from Hungary, Bohemia, etc.) and therefore considered as such in the classification. Still, the fish were included in the analysis because the carp reflect the fish demand of the Viennese population very well. There were two clear peaks in the delivery, the first at Easter and the second at Christmas (Fig. 74).

Figure 75: Monthly delivery (in kg) of tench to the Viennese fish market from 1881 to 1893 (top left) and from 1904 to 1914 (top right). Closed season in June. Monthly delivery (in kg) of wels to the Viennese fish market from 1881 to 1893 (bottom left) and from 1904 to 1914 (bottom right). Closed season in June.

The tench and the wels had their closed season during June (Fig. 75 top & 75 bottom). Krisch (1900) stated that the fish mainly came from Upper Austria in the Austrian Danube. The tench appeared throughout the first period also during its closed season, but had no deliveries in November. The appearance during the closed season might be due to deliveries from fishponds in Bohemia and the Danube in Hungary (see above and Krisch, 1900). For the second period it was less frequent on the market during its closed season. It can be assumed that the tench came from the Austrian Danube, though not entirely (see above). The wels declined in both time spans during its closed season in June, but was never absent. This indicates that the wels did not come entirely from the Austrian Danube. According to Krisch (1900), the wels' delivery to the fish market originated from the Middle and Lower Danube (Hungary, Romania), lakes (Lake Balaton, Carinthia), rivers (Tisza, Drava, Save, March) and fishponds (Bohemia, Moravia).

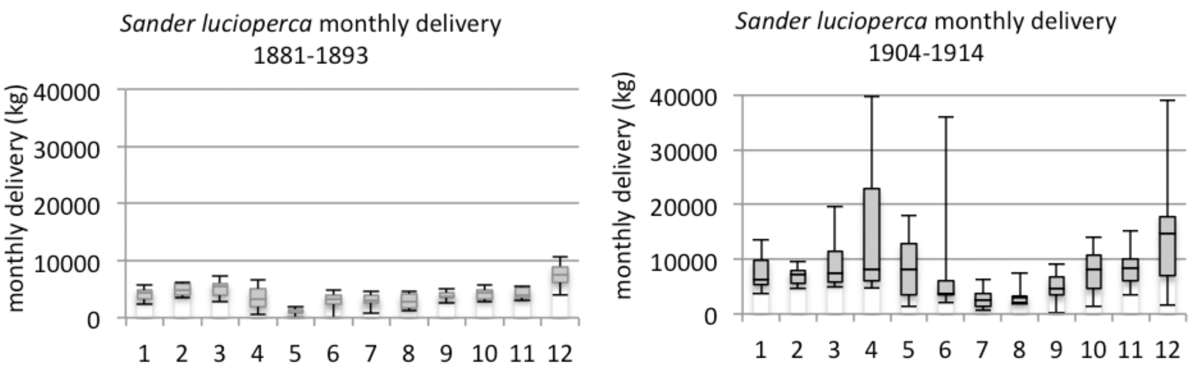

Figure 76: Monthly delivery (in kg) of pikeperch to the Viennese fish market from 1881 to 1893 (left) and from 1904 to 1914 (right). Closed season from the middle of April to the end of May.

The pikeperch was delivered during its closed season from the middle of April until the end of May. Yet the numbers were higher for April, so they could have been delivered before the closed season started (Fig. 76). Another reason could be that the pikeperch were delivered from other places, like fishponds in Bohemia and Moravia, the Middle Danube (Hungary), other rivers as the Danube (Tisza, Save, March, Braila) (see above and Krisch, 1900).

4.4.3 Analyzing changes in delivery of fish species

With the yearly deliveries of potential Danube fish species to the market, it was possible to examine the distribution of fish sold over the years at the fish market. *Chondrostoma nasus* appeared as an independent species only once in the data, therefore no graph is shown. Instead the nase was likely incorporated in the delivery of "whitefish", where it contributed to the high numbers (see Fig. 77 – 86).

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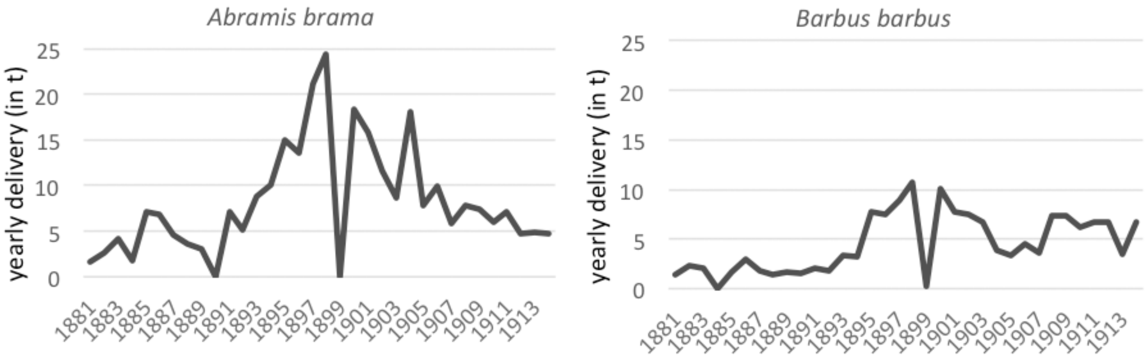
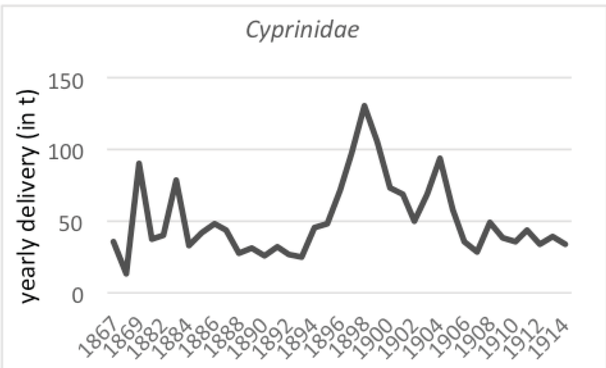


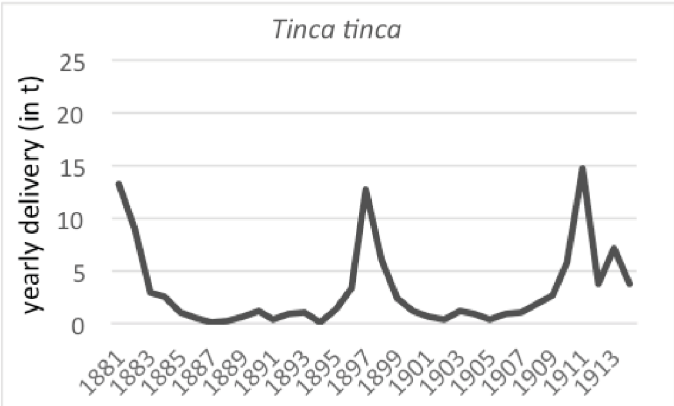
Abramis brama
yearly delivery (in t)
25
20
15
10
5
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913
Barbus barbus
yearly delivery (in t)
25
20
15
10
5
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913

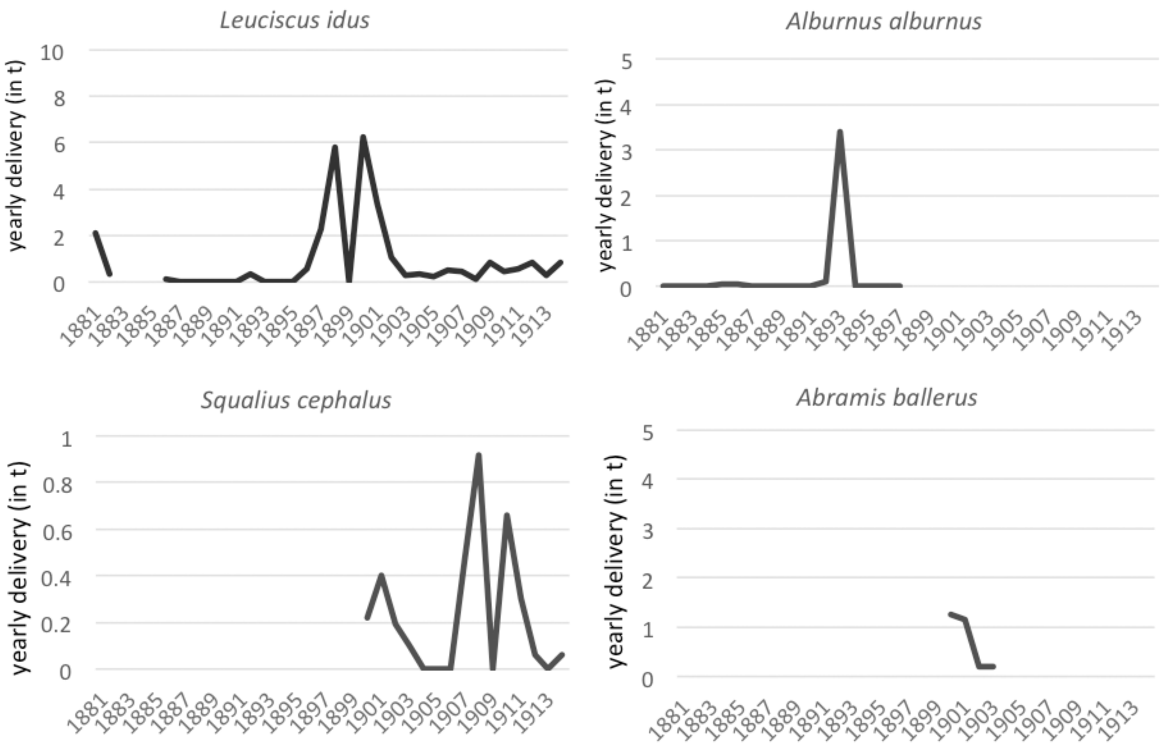
[illegible]

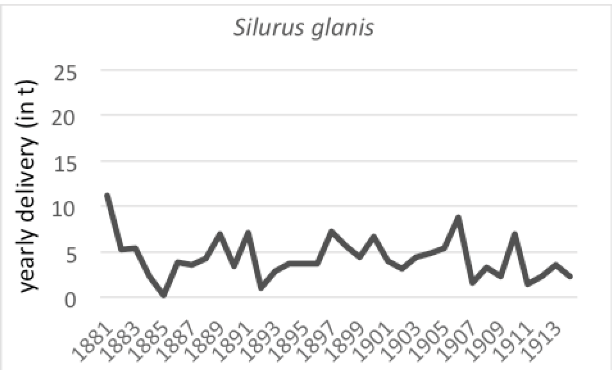


Cyprinidae
yearly delivery (in t)
150
100
50
0
1867
1869
1882
1884
1886
1888
1890
1892
1894
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914

[illegible]


Tinca tinca
yearly delivery (in t)
25
20
15
10
5
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913


Leuciscus idus
Alburnus alburnus
Squalius cephalus
Abramis ballerus
yearly delivery (in t)
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913


Silurus glanis
yearly delivery (in t)
25
20
15
10
5
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
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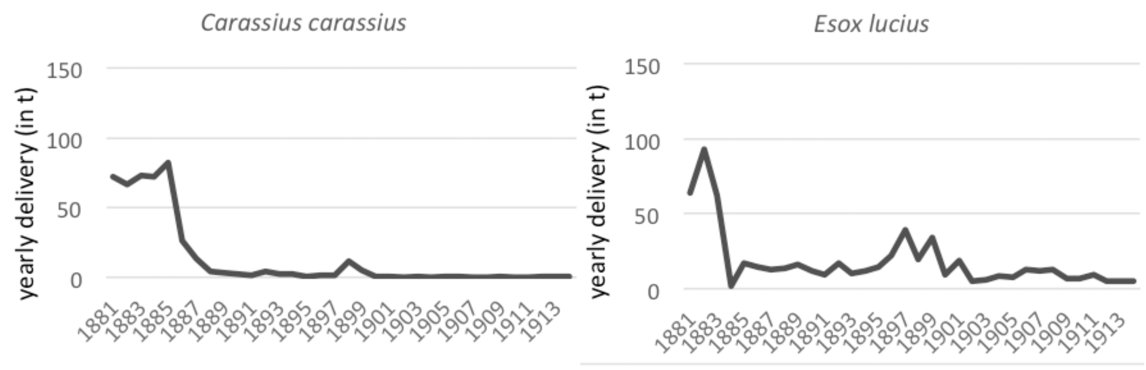
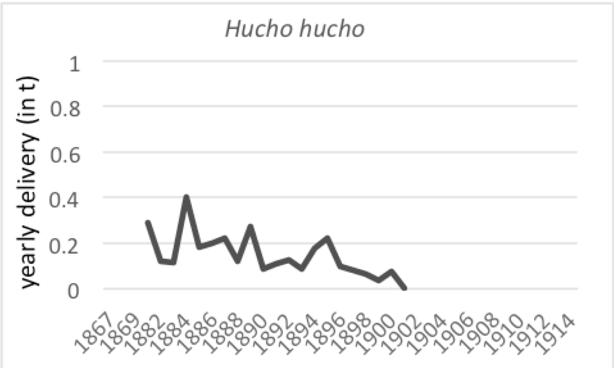
1907
1909
1911
1913


Carassius carassius
yearly delivery (in t)
150
100
50
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913
Esox lucius
yearly delivery (in t)
150
100
50
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
1911
1913


Hucho hucho
yearly delivery (in t)
1
0.8
0.6
0.4
0.2
0
1867
1869
1882
1884
1886
1888
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1892
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1896
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1900
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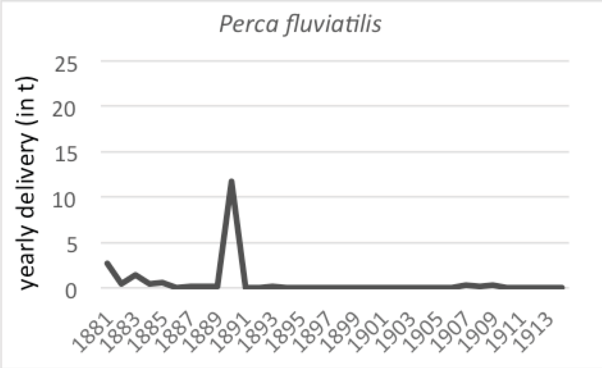
1904
1906
1908
1910
1912
1914


Perca fluviatilis
yearly delivery (in t)
25
20
15
10
5
0
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
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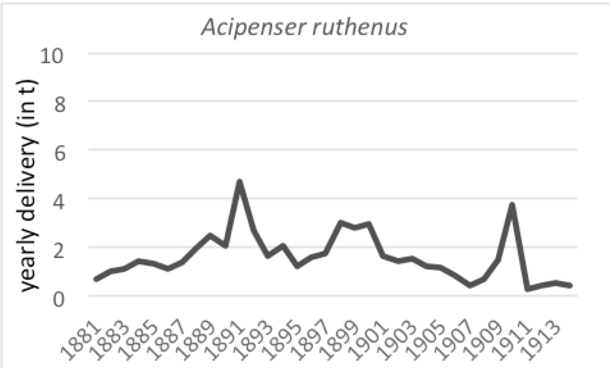
1907
1909
1911
1913


Acipenser ruthenus
yearly delivery (in t)
10
8
6
4
2
0
1881
1883
1885
1887
1889
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1893
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1897
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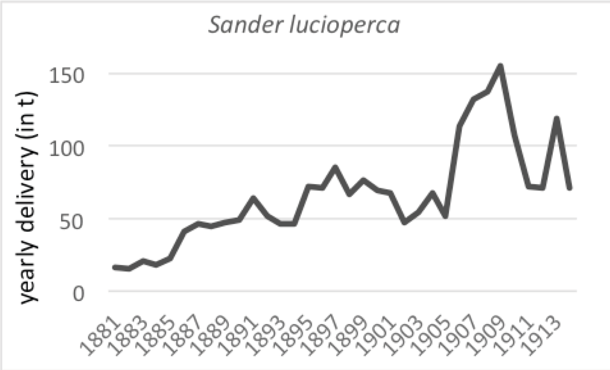
1907
1909
1911
1913



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ti sOW tK Ktk- Dt D ti pOhDk WäUr äKt KWi UaiK- täUt ö dB Bmi öd ti ö dUt d diB- iOl CKädsk O- iO D B K DUkdKD Dh hi Bmi On Dt OkpstkpD ti Wi Ck n KDpnä nS tikWt äBU KWi UaiK d n KWi UBBhBo dkWt äBU KWi UaiK dpo iOK hi UBdin hOR DUBBhS diOR kd rkOD ti hi UBdi o ästD mi iid Dt D Otik Wt äBUd nBo dkWt äBU diin Dt i ämi OKi (pD äUt äD K Dt D - iOl ni KDOk hin npi Dk ti KhKD o D äU ami OUt d di BwD äkdS

wqK ao sf Lsaf avar mUc S s dLcS LS cnd f Uvsdr b cynL U L

wqKqP accndl af Unf n f mdsd avsdr U L vcao P22P D P: Pw

äOKD Dt i räKt hD - i O B hwi n pKäds UkO KWkdni dU B hKäK n Dt i o WkO U kr Dt i Uko Wkdi dDK K K Ki KKi n 1 B 85N

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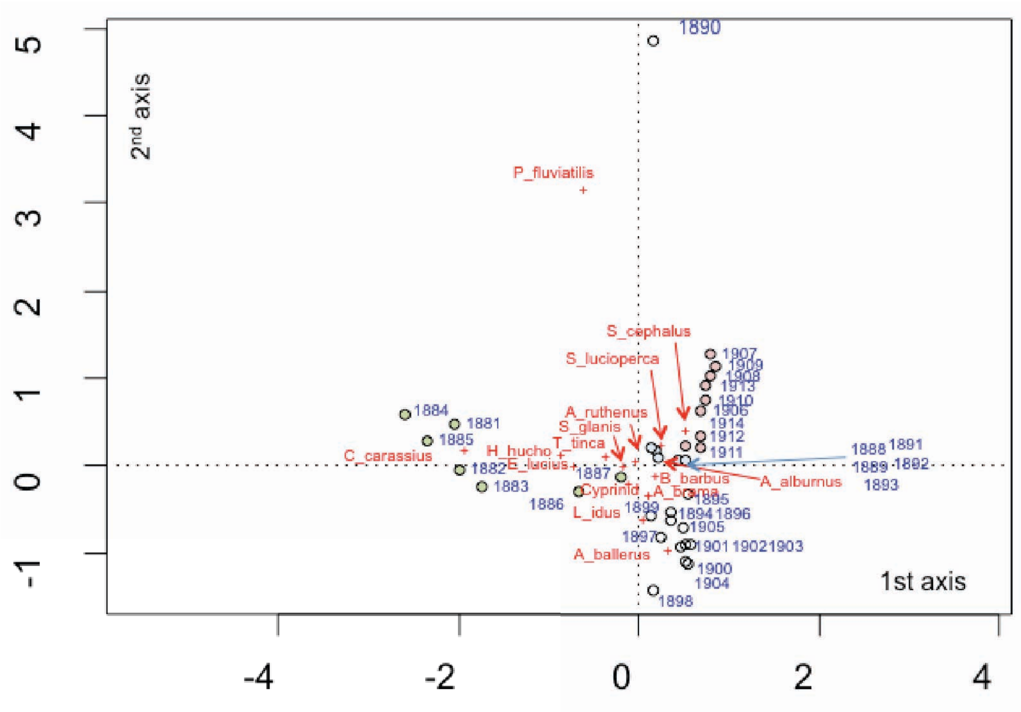
senf V Sn	PSTö8E	PSP96T8	PSP6696	PSPöz88
cal acLsaf	PS88T8	PSJEEöE	PSJP9PT	PSP9zöö
pl sf nU				
So S LsVn	PS88T8	PS698zE	PS9xEz8	PSx6ETz
cal acLsaf				

ti räOKDA äK K Dt i o kKD o WkO DGKt k- äds Dt i dni Wi dni dD D ä B KS AW di n o kO Dt 88ß kr Dt i Dk B adi OD 1PS6ET95 ti E[dn] A äK Ukd D di n Dt i ni Wi dni dD D ä B KS ti J[KD] Uk O KWkdni dU B hKäK J5 K Dt i o kKD o WkO DG Dt i E[dn] U i Ukd Käni O nG pD T n ö U i disB U nG i U Ki Dt i räOKD D k B O h i AW di n o kO Dt 69 ß 1adi OD S



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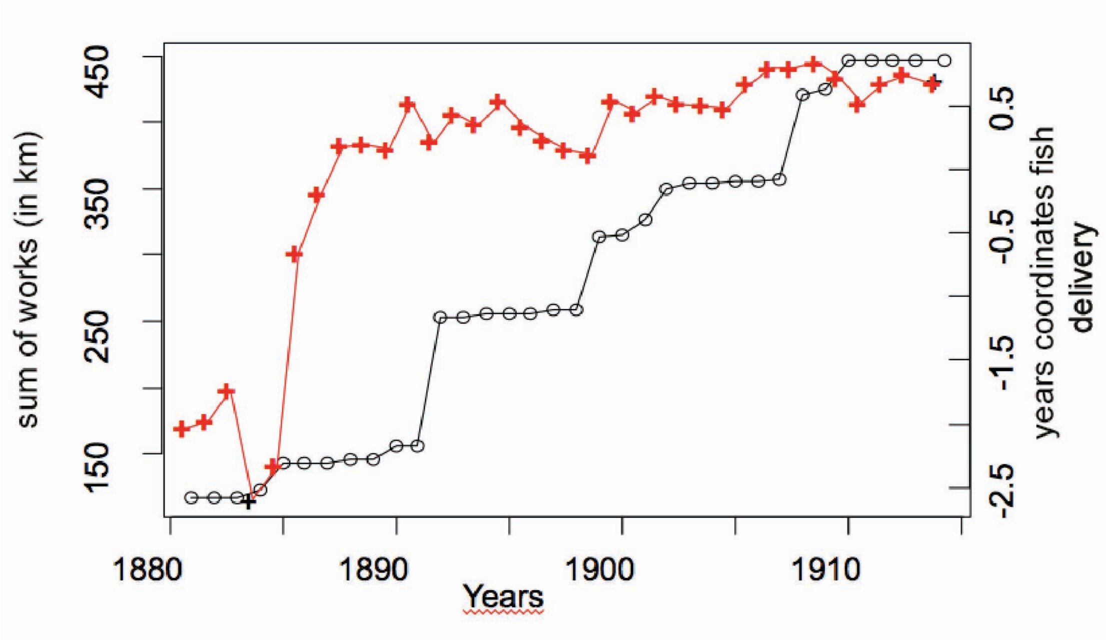
sum of works (in km)
450
350
250
150
years coordinates fish delivery
0.5
-0.5
-1.5
-2.5
1880
1890
1900
1910
Years

wqKq] f af s accndl af Unf n f mdsdg sf y en nLD nnf nf esf nncsf e D acyd f UAvsdr ncm

rD OD i Ki WD D i d B hKi Krk OD i rKt nD G D i Ki rKt nD d n D i O sp D äk d nD - i O

Uko WD i n d Uko ädi n S t i Uko o d n rk OD äK K üK K rk B k- K N

uB C n O n L C v v n v o O di

5j 9 v : o i l TF vou FTvog 4

	f ncLs	cal acLsaf	f y
aL	PS6ET9	JSPPPP	
af dLc sf nU	PSEz8z	PSö9öö	ö
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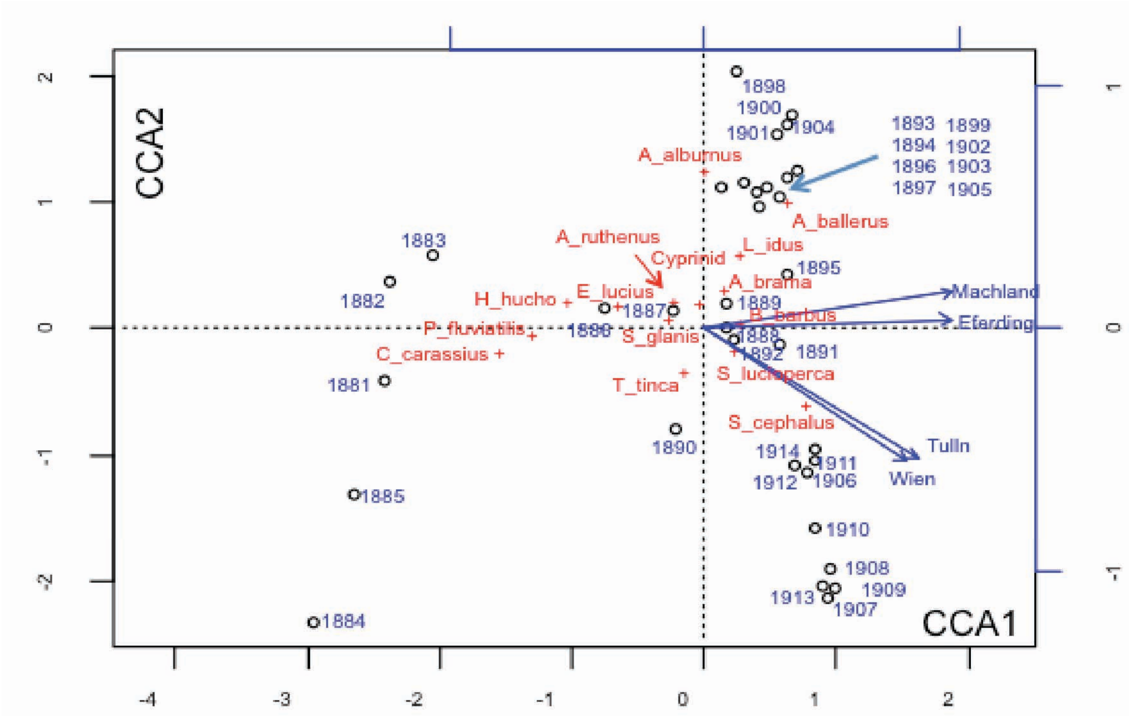


ui pv Db9 T2 u : T: u Tvv l hT: : : f l u l TF og Fl g F p: : og g f v p u l ovp opv l 4

t i KDQp UDpO k r D t i rKt rp d - K mi Oh Käo äB D k D t i k di k D di n - äD D t i Käo WB

Uk OO KWkdni dU d B hKäK 1 ä S xz 5S D rk B k- K D t i d D D D t i t hnO B U KDQpUDpO K i AWB di n most of the changes in the fish composition. Hydraulic structures in Wiener Becken and Tullnerfeld seemed to be more important for the second period (2nd axis, 1906 to 1914), the majority of the construction work happened in this area. In the first period (1st axis, 1881 to 1887) most of the constructions took place in the Machland and Eferding.

The analysis proved that almost 50% of the changes in the fish delivery were due to the hydraulic structures in the Danube. This was quite significant considering the multitude of factors which had their various influences on the species composition.

5 Discussion

5.1.1 Hydraulic structures along the Austrian Danube

The analyses of the hydraulic structures along the Austrian Danube, from 1865 to 1914, proved that the aquatic habitats were changed due to the installation of hydraulic structures (e.g. mean flow regulation and low flow regulation). In detail the results showed that the mean flow channelization of the Danube, executed between 1870 and 1900, altered the riverine ecosystem drastically, due to the decoupling of the floodplain. Although as early as at the beginning of the studied period, hydraulic structures which existed along the Austrian Danube fluvial dynamics could still work, as is visible in 12% of connection intensity in comparison to 5% in 1910. Consequently, the results for the Austrian Danube corroborate former research in different areas along the Austrian Danube (Hohensinner et al., 2004; Schiemer & Waidbacher, 1992; Schmautz et al., 2000). Particularly harmful for the aquatic habitat composition was the development of hydraulic structures on both sides of the river and a regulated river width (less than 400 m). The goal was to concentrate the discharge into one single channel. Large artificial backwater systems gradually diminished or transformed into isolated water bodies (Plesiopotamon). Riverbed incision and the lower groundwater level accelerated the terrestrialization processes visible in the increase of bank protections mapped during the period studied. The results showed that these structures increased drastically, most likely due to the aggradation processes behind closured dams and training walls as of 1890. A degradation of the river took place, as habitat rejuvenation was not possible anymore and altered the aquatic habitat composition (Hohensinner et al., 2011; Schiemer & Waidbacher, 1992). The intensity of lateral hydrological connectivity between main arm (Eupotamon A) and the different kinds of side arms in the floodplain area is of high importance for the ecological functioning of an aquatic environment.

The individual development of hydraulic structures along the four different basin stretches could also be analyzed. Construction periods in the single basin stretches were defined and trends shown. In Upper Austria most of the hydraulic structures were installed by 1892 in the Eferdinger Becken and the Machland. As the literature analysis showed in these stretches, the systematic river channelization started earlier, for instance in the Machland the river got already straightened around 1830 (Hohensinner et al. 2011; Baumgartner, 1862; OÖ Statthalterei, 1909). The majority of hydraulic structures in Vienna were executed between 1870 and 1880, including the excavation of a new riverbed, the mean water regulation and the installation of flood protection dykes. In Lower Austria, the increase of hydraulic structures started after 1880, when the Great Viennese Danube regulation was finalized. A second period of constructions could be detected from 1898 to 1910 in both basin stretches, mainly due to the finalization of the mean flow regulation in Lower Austria and the low flow regulation (Donauregulierungs-Kommission, 1898; 1909).

5.1.1.1 Source critique - hydraulic structures

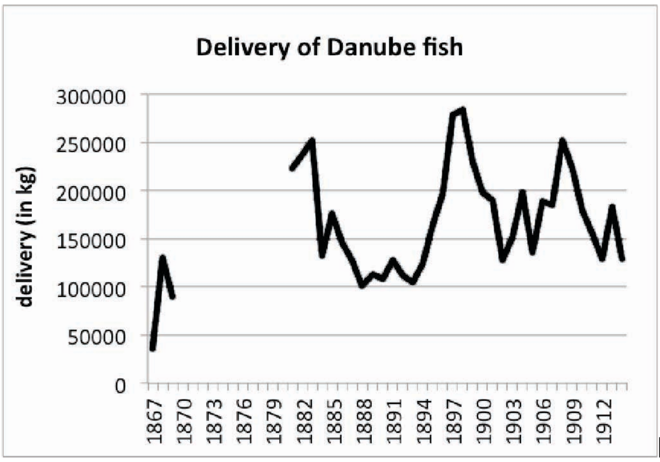
The reconstruction of the hydraulic structures along the Austrian strongly depended on the available sources. As the historical maps were not produced for a spatially and temporally high-resolution reconstruction of the aquatic habitat composition various problems were encountered during the mapping process. Especially in the case of the naturally dynamic riverine landscape with its diverse and often short-lived structures (different types of water bodies, gravel banks, etc.), maps were often created with a rather generalized approach. Another problem could arise with the cartographer who might have omitted specific structures depending on the purpose of the respective map. Still, all three considered maps made it possible to reconstruct the hydraulic structures along the Austrian Danube. As Hohensinner et al. (2013) describe the critical reading of sources is essential for the reconstruction process, as today, the remains of the hydraulic constructions no longer exist, or were buried in the ground. The GIS-based reconstruction yields three georeferenced maps that chronologically display altered states of fluvial landscapes, i.e. increasing hydraulic structures. During the mapping process various information could be added to the hydraulic structures in ArcGIS (length, geographical position, construction date, etc.) and be compiled in one dataset. The reconstruction of the hydraulic structures combined historical sources with information about typical fluvial processes. During the mapping process of hydraulic structures one was forced to think about the historical development of the structures. One major problem was the exact reconstruction of the construction date of the hydraulic structures. The historical maps and the literature described periods of usually 20 years, but the further analysis in combination with the fish market data required single years. In the 3rd Military Survey in particular, discrepancies between the construction date given in the map and the literature appeared. After investigations of further maps, as the evidence maps of the 3rd Military Survey the dates could be corrected. This process was rather time consuming and required skills in reading dated handwritings.

5.1.2 Fishery practices

The impact of hydraulic structures on the fishing practices in the Austrian Danube was not possible to examine due to a lack of information. Intensive literature analysis showed links between the decline in fish species and the river regulations and the difficulties fishermen had to face at the time, but precise changes of the fishing methods were not documented. One likely reason might be that no drastic changes took place, considering the fishing practice.

5.1.3 Fish market data

It was possible to link the historical statistics of the Viennese fish market data with the habitat change and thus actual fish composition of the Austrian Danube. The fish market registers contained sufficient information about the fish species and their abundances on the Viennese fish market to execute a quantitative analysis. Changes in the fish composition could be related to the ecological preferences of the Danube fish species, as the flow conditions (after Schiemer & Waidbacher, 1992). The provenance of the fish was not known, hence a classification needed to be established to determine the Austrian Danube fish species. It was possible to test the provenance of the potential Danube fish species comparing monthly delivery data with legal regulations (the closed seasons). The results of the monthly data showed delivery patterns of the Austrian Danube fish and the farmed fish (in this thesis mainly carp) delivered to the Viennese fish market. Two peaks throughout the year were detected, at Christmas and Easter, dominated by carp. The Danube salmon was delivered in late autumn and winter. Sometimes the Danube salmon appeared between January and April, during its closed season from the middle of March to the end of April. It could be assumed that these specimens were delivered from other places (e.g. tributaries, Hungarian Danube) (Migl, 1905). The provenance of the fish for the analysis was very important and needed to be considered carefully, visible in the comparison between the two graphs for the total supply to the Viennese fish market (Fig. 90 & 91). The latter excluded pikeperch from the deliveries, because they were often from Hungary, especially in the 20th


Delivery of Danube fish
delivery (in kg)
300000
250000
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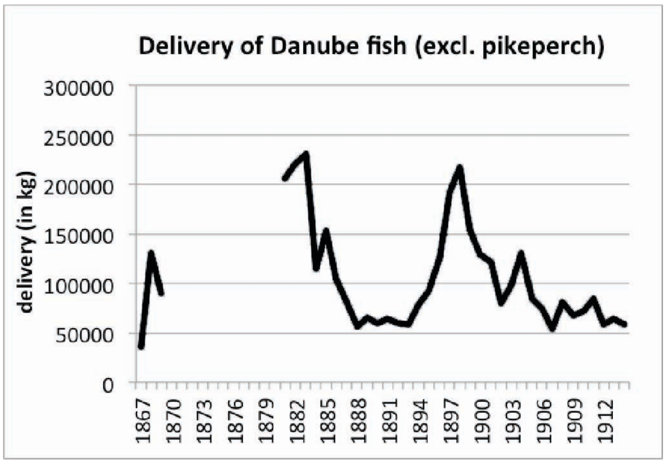
Delivery of Danube fish (excl. pikeperch)
delivery (in kg)
300000
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1897 and 1899. The absence during certain years may be linked to flood events or other periodic events. Further studies will be needed to examine the reasons. The results of the fish market data showed a change in the fish community from limnophilic to rheophilic and finally eurytopic species as described in previous studies related to the river channelization in Austria before (Schiemer & Waidbacher, 1992; Haidvogl & Pont, 2013). In general Danube fish species declined on the market.

For further analyses it would be recommendable to exclude pikeperch and wels from the potential Danube fish species, because it was unsure whether this fish came form the Austrian Danube or other places, or if the prominence changed throughout the period studied (e.g. origins Krisch, 1900).

5.1.3.1 Source critique fish market data

The critical evaluation of the sources concerning the fish composition in the Austrian Danube was necessary for the correct interpretation and analysis (Haidvogl et al., 2014; Zauner & Eberstaller, 1999). It had to be considered that the documented information of the Viennese fish market registers may be lower than they were in reality for the purposes of avoiding taxes and for the fact that they focused on commercial species. It is important to recognize that the fish market data were produced within the larger framework of fisheries economy and therefore did not reflect local conditions, as for instance the hydraulic structures along the Austrian Danube. Nevertheless, it was possible to link the fish market data with the changes in the fish composition. The fish market data cannot reconstruct the entire past fish fauna of the Danube as only commercial fish were delivered to the market. Furthermore, the preferred fish species of the customers can be detected in the data, considering all fish species delivered to the market. For more detailed arguments about the societal preference of the population the fish prices should be considered and could be the next step in future research.

5.1.4 Combination of hydraulic structures and fish market data

The results of the combined analysis ascertained the assumptions about the relation between hydraulic structures and potential Danube fish species from the Viennese fish market data and unraveled temporal interactions. In the beginning of the studied period limnophilic species, as tench and Crucian carp were still delivered to the fish market. They declined drastically or disappeared in the market registers during the installation of the mean water regulation (around 1895). One explanation might be that the fish species were probably from the backwaters or bays of the main channel, which disappeared due to the channelization. From 1890 on rheophilic species, as burbot, barbel, ide and zope dominated the deliveries; as these fish species prefer faster flow conditions. The combined analysis showed that during the period from 1880 to 1890 the engineering works influenced the fish assemblage the most. Reasons for this might be the intensive engineering works happening along the Austrian Danube to finalize the mean water regulation. Each type of hydraulic structures (closure dam, training wall, bank protection) had different impacts on the fish species. In the combined analysis, however, it was not possible to distinguish between the different regulation measures, because they were highly correlated and they could not be considered separately. For that reason, all the hydraulic structures of each basin stretch (Eferdinger Becken, Machland, Tullnerfeld, Wiener Becken) were compared with the potential Danube fish species. Hydraulic structures in the Wiener Becken and Tullnerfeld seemed to have bigger impacts on the fish composition during the period from 1906 to 1914. According to the location of the fish market in Vienna it could be assumed that many fish were delivered from this stretch. Another reason might be that most of the hydraulic structures in the Eferdinger Becken and Machland were already completed. The results of the combined analysis revealed a shift from limnophilic to rheophilic and later eurytopic species that was to 50% caused by the hydraulic structures installed along the Austrian Danube. Considering the multitude of factors (e.g. overexploitation of juveniles, illegal fishing during closed seasons, fish farming, marine fish species, industry, water pollution, etc.) influencing the fish abundances at the Viennese fish market the result is quite significant. The results also support recent research that the terrestrialization and habitat fragmentation not only reduced limnophilic species, but also reduced the habitats for rheophilic organisms in formerly lotic water bodies. In addition, the migratory pathways for fish species relying on the floodplain as spawning and nursery sites were interrupted (Schiemer & Waidbacher, 1992). The decoupling of the floodplain also constrained the exchange pathways of water, nutrients and aquatic organisms between the main channel and the divers floodplain biotopes (Jungwirth et al., 2003; Tockner et al., 2000a, 2000b). Fish need different types of flow regimes for different life stages, including species that mainly inhabit the main channel. They need side arms and backwaters for the food collection, as winter refuge and as spawning- and nursery sites.

6 Conclusion

The thesis contributes to the reconstruction of the past Austrian Danube fish composition during the 19th and early 20th century. In the course of this thesis, it was shown that the fish composition of the Viennese fish market data is related to the actual fish composition of the Austrian Danube and can be proven by reconstructing the habitat conditions and its changes from 1865 to 1914. Hence, the first hypothesis was proven to be true and throughout the analysis the second hypothesis was approved as well, stating the negative impact of the Danube regulation on the aquatic habitat composition and the fish community. The third thesis could not have been dealt with due to insufficient data concerning the impact of the hydraulic structures on the commercial fishing practices in the Austrian Danube.

The combination of fish trading data with fishing laws (closed seasons) enabled to prove assumptions about the provenance of fish brought to the market and in particular to identify potential Danube fish species. The presence and abundances of 15 Danube fish species delivered to the Viennese fish market were successfully analyzed. These data were gathered from the Viennese fish market registers and contemporary literature (Krisch, 1900; Peyrer, 1874; etc.). The spatial analysis in ArcGIS enabled to reconstruct hydraulic structures and changes in the aquatic habitat composition along the Austrian Danube for three observed time periods between 1865 and 1914. Correlations between the fish market data and the hydraulic structures could be proven, making it possible to assign hydraulic structures of the four basin stretches (e.g. Eferdinger Becken, Machland, Tullnerfeld, Wiener Becken) to specific fish compositions delivered to the Viennese fish market. Up to 50 % of the changes in the fish composition of the Danube fish species delivered to the fish market were explained by the habitat changes in the Austrian Danube. These changes were mainly due to the systematic river channelization of the Danube that altered subsequently the fish composition. As such, systematic regulation fundamentally altered the natural river characteristics and transformed the anabranching river system of the Austrian Danube into a channelized stream. The influence of the changed habitat conditions on the fishery practices in the Austrian Danube was due to insufficient data not possible to investigate but it was probably not very strong.

The method showed the possibility to reconstruct the fish composition of the Austrian Danube with statistical data from the Viennese fish market. It might act as example for using similar types of data and methods for other rivers. The findings might support the definition of historical reference conditions better reflecting a more dynamic state of the Austrian Danube than nowadays, as needed for river restoration measures. The present study corroborates that the biodiversity of an intact riverine ecosystems is closely related to the habitat composition and that their development, both depend strongly on natural fluvial disturbances (Hohensinner et al., 2011; Ward, 1998; Arscott et al., 2002, Tockner et al., 2006).

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8 Appendix

8.1 Findings in the Evidence Map of the 3rd Military Survey

During the georeferencing process of the Francisco-Josephinische Landesaufnahme remarks on the map sheets that altered the date of the regulations installed in the Danube were found. To prove the findings further investigations at the BEV were necessary to examine changes made to the map after the years 1875. Remarks on the side of the map sheets showed handwritten notes that hydraulic structures were inserted after 1875. One example of these remarks: *"Danube correction year 1892".* Besides the difference in the marking of the regulation works according to different painters also the date became insecure. Thanks to the head of the historical maps department at the BEV, Hr. Knoll, the original map sheets could be examined for changes. The maps of evidence were an important source in determining the age of the hydraulic structures. All changes made after the finalization of the map were inserted in these maps until the production of a new map. Most of the evidence maps date until the beginning of the 1900's and include the low flow regulation. Important was now to detect regulations that already existed prior to 1884 and 1892, because the changes made in the map from the 1890ies might already have been constructed in the 80ies. To minimize the time period a map from the Danube Regulation Commission from 1881 was used to compare the state of the regulations. However, a lot of the inserted corrections refer to a protocol number unfortunately these notebooks were not available and might be lost. The interesting point in this finding is that usually alterations after the production of the map, besides transport infrastructures, were not added to the original map. Possible explanations why the Danube regulation was adapted in the map might be to the importance of the Danube as transport way, or an external order from an agency to conduct the drawing of the regulations into the map. The changes were inserted via scrapping the old paint off and drawing the new regulations, the changed forms of gravel banks and the river mouths into the map. This can be seen by the white shades around the blue surface of the water body and the roughness of the paper. Another hint was the thicker lines and triangular shaped constructions. The construction date of the regulations could be altered, for the ones that were added later. Some regulations only were drawn into the original map but not into the evidence map. Regulations appearing in both maps have the same age as initially assumed for instance, 1875.

8.2 Tables

Table 17: Used fishing gear as described in Krafft (1874-)

Krafft Fangwerkzeuge Flussfischerei	Art	Masse	Provinz
	Grundgarn	45 Klafter und 4 Fuß hoch	Lower Austria
	Segengarn mit Bleiohren und Flossen	10 bis 40 Klafter lang	Lower Austria
	Setzgarn mit Bleiohren und Flossen	30 bis 40 Klafter lang	Upper Austria
	Leitergarn mit Bleiohren und Flossen	30 Klafter lang	Upper Austria
	Wadgarn		Upper Austria
	Gewöhnliches Setzgarn		Upper Austria
	Fürgarn		Upper Austria
	Laubengarn		Upper Austria
	Kampgarn		Upper Austria
	Huchengarn		Upper Austria
	Tauchgarn		Upper Austria
	Garnl mit eisernen Lagen		Upper Austria
Barren oder Bären:	Setzbär		Upper Austria
	Streichbär	zum einzelnen Herausfangen der Fische nach beendigter Netzfischerei	Upper Austria
Taubel oder Hamen:	Setztaubel		Upper Austria
	Handtaubel		Upper Austria

Krafft Fangwerkzeuge Flussfischerei	Art	Masse	Provinz
Reusen oder Reispen:	Flügelreusen		Upper Austria
	Zwirnreusen		Upper Austria
	Huchengeher		Upper Austria
	Gewöhnlicher Geher		Upper Austria
	Binsenreusen		Upper Austria
	Strohreuseln		Upper Austria
Fallen:	Gewöhnliche Fischfallen (in den Mühlbächen)		Upper Austria
	Ottereisen		
	Huchenfallen		
Angeln:	Rad und Angel		Upper Austria
	Gewöhnliche Angeln samt Zugehör		
	Leg- oder Nachtschnur	30 Klafter lang	Upper Austria
	Künstliche Mückenschnüre		Upper Austria
	Angel mit Seidendarm		Upper Austria
	Speere (Harpune oder Stecheisen)		
	Stechgabeln		

8.3 Work steps for the georeferencing

1. Load tiff-picture to table of contents
2. Open *Arctoolbox* – data management – projections – define projections
3. Define projection: MGI Austria Lambert
4. Zoom to layer
5. Choose layer and already georeferenced layer via import option – ok
6. Start georeferencing with setting of control points at least 10 for one picture
7. Spline – 10 control points- Interpolation: Spline
8. Switch off auto adjust choose editable layer start setting control points
9. Save control points
10. Auto adjust on
11. Zoom to layer
12. Update
13. Rectify
14. No data as 1 especially for black-white maps, as the Pasetti-map
15. Save as tiff
16. Ok
17. Load rectified picture into ArcGIS

9 List of Figures

10 List of Tables