Typology of historical sources and the reconstruction of long-term historical changes of riverine fish: a case study of the Austrian Danube and northern Russian rivers

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Abstract – Historical data are widely used in river ecology to define reference conditions or to investigate the evolution of aquatic systems. Most studies rely on printed documents from the 19th century, thus missing pre-industrial states and human impacts. This article discusses historical sources that can be used to reconstruct the development of riverine fish communities from the Late Middle Ages until the mid-20th century. Based on the studies of the Austrian Danube and northern Russian rivers, we propose a classification scheme of printed and archival sources and describe their fish ecological contents. Five types of sources were identified using the origin of sources as the first criterion: (i) early scientific surveys, (ii) fishery sources, (iii) fish trading sources, (iv) fish consumption sources and (v) cultural representations of fish. Except for early scientific surveys, all these sources were produced within economic and administrative contexts. They did not aim to report about historical fish communities, but do contain information about commercial fish and their exploitation. All historical data need further analysis for a fish ecological interpretation. Three case studies from the investigated Austrian and Russian rivers demonstrate the use of different source types and underline the necessity for a combination of different sources and a methodology combining different disciplinary approaches. Using a large variety of historical sources to reconstruct the development of past fish ecological conditions can support future river management by going beyond the usual approach of static historical reference conditions.

Key words: Historical fish communities; written sources; Austrian rivers; Russian rivers; Historical ecology

Introduction

Ecological assessment and restoration targets are often linked to natural conditions of ecosystems exposed solely to natural variability. When reference sites are no longer available, the conditions prevailing in past ecosystems are usually considered as adequate substitutes (Swetnam et al. 1999; Egan & Howell 2001; Stoddard et al. 2006). Today, however, this concept is discussed controversially either because it is impossible to return to historical states (Dufour & Pégay 2009) or because adequate historical data are difficult or impossible to obtain and apply (Szabo & Hedl 2011).
Historical conditions were first employed as references by forest ecologists (Kaufmann et al. 1994) and later adopted for aquatic systems to help develop conservation targets and legal regulations (USA Clean Water Act: United States Congress 1972; Karr 1981). The most important legislations for European rivers include the Water Framework Directive (WFD, European Commission 2000) and the Flora, Fauna, Habitat Directive (FFH, European Commission 1992), which refer to the ‘native status of species’ (FFH) or to ‘natural conditions’ of rivers, lakes and estuaries (WFD).

Over the last 15 years, numerous studies have used historically based reference conditions to compare them with the present ecological situation and to evaluate pressures caused by humans. Wolter et al. (2005) analysed printed fish biological documents especially from the late 18th and 19th centuries to reconstruct species compositions and relative abundances in the Oder and Elbe Rivers. Winter et al. (2009) relied on similar sources for the Dutch Vecht River. The investigation of the fish fauna of the French Rhône by Carrel (2002) was based on maps from the early 20th century. Worthington et al. (2010) defined a conservation programme for burbot (Lota lota) in the UK based on its occurrence in the 19th century. Various articles edited by Rinne et al. (2005) or more recently by Maceda-Veiga et al. (2010) investigated changes in the structure of fish communities based on records from the past 100–150 years.

Most studies employed printed fish biological and fishery literature or fish distribution maps from the late 18th to the early 20th century. These sources enable compilation of species lists and in some cases estimations of relative abundance. In most cases, the results were combined to one static fish ecological situation before major human impacts are even considered to represent ‘pristine conditions’, against which ecological assessments can be made and restoration targets formulated. This approach, however, is based on the assumption that major human modifications of riverine fish communities started with the systematic construction of (flood protection) dykes, hydropower dams and large-scale organic and chemical pollution during and after the 19th century. It is certainly true that the magnitude of human impacts intensified considerably as a consequence of industrialisation. As Humphries & Winemiller (2009) stated, however, anthropogenic influences and subsequent changes in freshwater fish populations can be traced back several centuries. For example, intensive exploitation of fish and stocking has occurred since the Middle Ages. Widespread pre-industrial societal activities in and along rivers – such as wood rafting or hydropower use with mills – modified fish habitats, harmed eggs, larvae and juvenile fish, and hampered their live cycles, for example, by blocking spawning migrations (Lenders et al. 2007; Hoffmann 1996). Fish communities and populations also fluctuated depending on climate or natural disturbances induced by extreme floods – all in the absence of human interventions (Pont et al. 2009).

Analysing the historical interactions between human activities, climate change and riverine fish communities and populations has gained increasing importance beyond studies motivated by the search for reference conditions. Such research has been undertaken for a longer time in marine (fish) ecology, as demonstrated by the ‘History of Marine Animal Populations’ project, which considered a long-term approach and focused on human–ecosystem interactions (Holm et al. 2010). Important concepts such as the ‘shifting baseline syndrome’ (Pauly 1995) and ‘fishing down the food web’ (Pauly et al. 1998) were developed, and comprehensive reviews were published (Jackson et al. 2001). This encourages further, profound historical and ecological studies on riverine fish, which will help reveal past trends in fish community and population development and improve our understanding of potential future trends, for example, climate change and biological conservation (e.g., Lassalle & Rochard 2009).

The search for and analyses of historical long-term data are complex and challenging. A greater number of fish biological surveys are available only since the 19th century. Nonetheless, a focus on these sources underestimates the influence of pre-industrial societies on fish populations. Moving further back in time requires using sources originating from activities other than those involving fish biology. This calls for developing approaches and methods for their application.

This article discusses which types of printed and archival historical sources are available to reconstruct the development of riverine fish communities from the Late Middle Ages until the mid-20th century. Based on recent studies of the historical fish fauna of the Austrian Danube and northern Russian rivers, we propose a classification scheme for historical sources. In a second step, we demonstrated how these different sources can be used to reconstruct fish communities (Salzach catchment as a Danube tributary system) and to analyse changes in fish populations (Russian rivers, Danube).

Material and methods

Study sites

The classification of sources was based on written records available in various libraries and archives for selected Austrian and Russian rivers (Fig. 1).
The Russian North is a vast area that covers rivers of the White and Barent Seas. The largest and most important in terms of fishing are the Pechora, the Northern Dvina, the Mezen, the Onega, the Vyg, the Kem and the Varzuga. There are also many smaller rivers. The climate is quite cold, and the rivers are usually ice-covered from October/November until May. In total, about 30 fish species inhabit the rivers today. Anadromous species (Atlantic salmon *Salmo salar*, trout *Salmo trutta*, rainbow smelt *Osmerus mordax*, whitefish *Coregonus lavaretus*) are the commercially most important. Typical European freshwater species also occur (roach *Rutilus rutilus*, perch *Perca fluviatilis*, pike *Esox lucius*, burbot *L. lota*, ruffe *Gymnocephalus cernuus*, ide *Leuciscus idus*). All species are native except the pink salmon, *Oncorhynchus gorbuscha*, which was intentionally introduced from the Russian Far East in the mid-20th century. As anadromous species are most important, fishing usually concentrates in the lower river sections and the mouths. This is also where most human settlements are located. In the larger rivers (Pechora, Northern Dvina, etc.), fishing also takes place in the middle or even in the upper sections. The Russian North is not rich in other natural resources, and opportunities for agriculture were limited. Forest industry first started to develop in the late 18th century and became the most important economic sector in the region. As anadromous species are most important, fishing usually concentrates in the lower river sections and the mouths. This is also where most human settlements are located. In the larger rivers (Pechora, Northern Dvina, etc.), fishing also takes place in the middle or even in the upper sections. The Russian North is not rich in other natural resources, and opportunities for agriculture were limited. Forest industry first started to develop in the late 18th century and became the most important economic sector in the region. Due to the very low population density, human-induced pressures on aquatic ecosystems were limited for a long time. Besides fishing, such pressures included forestry, which intensively used rivers for timber rafting, and dam construction in several rivers including the Kem and the Vyg.

For Austria, the present investigation focused on the Danube, around Vienna and Klosterneuburg, and the Salzach River as a Danube subcatchment. With a length of 2800 km, the Danube is the second longest European stream after the Volga. The river crosses ten European countries, and the catchment covers parts of 19 states and 817,000 km². The fauna exhibits a large diversity because, during the last glaciations, the lower Danube was a refuge for many warm-water-preferring species; in the Holocene, these species were able to recolonise the upstream sections. In total, 115 or about 20% of all European freshwater fish species are native here (Kottelat & Freyhof 2007; Sommerwerk et al. 2009). The Austrian Danube is roughly 340 km long. It is part of the upper river section that is characterised by a strong alpine influence, resulting in a comparably high slope and velocity. At the border to Slovakia, the mean discharge is 1890 m³·s⁻¹. The approx. 60 fish species inhabiting the Austrian Danube once included four diadromous sturgeon species, which are extinct today (Kottelat & Freyhof 2007). Thus, the fish fauna is now dominated by pure freshwater species, with cypfinds contributing the biggest proportion. The Salzach is a roughly 225-km-long tributary of the Inn, which is itself the largest tributary of the Upper Danube. The mean discharge at the confluence of the Inn is 251 m³·s⁻¹; the discharge regime is nival with glacial influence (Muhar et al. 1996). The native fish fauna of the Salzach comprises about 40 species, with the upper section and the tributaries being dominated by cold-water-preferring Salmonidae.

Anthropogenic influences on river ecosystems in Austria date back at least to the Middle Ages. In the 14th century, a dense network of large or medium-sized cities and villages with intense trade and commerce already existed. Austrian rivers served not only as food supplier but also as important resources for
energy, transport, water supply and waste discharge. In addition, land-use change along the rivers and within the catchments probably modified sediment input and fish habitats already in medieval times, as demonstrated, for example, by Bork et al. (1998) for Germany and discussed in Hoffmann (1996).

Archive search and written historical sources
This article uses written historical documents that potentially contain information on fish distribution and abundance. Working with texts preserved from the past is the traditional domain of historians (von Brandt 1958). They pose questions about relics from the past, thereby turning them into historical sources. Using a specific text as a historical source requires determining the producers and their motives to record something, but also reconstructing the usage and keeping of texts (Clanchy 1993). This is termed ‘source critique’, which is an essential element of historical methodology. Source critique helps to assess the informative value and significance of a text in answering a research question. The critical evaluation of the source therefore depends on basic questions. What did and could the producer know about the subject which is described? Was, for example, information about the occurrence and abundance of a fish species based on own observations in the field or on enquiries addressed to well-informed experts such as fishermen? Why, for example, was a specific fishery regulation produced? Was it to react to overexploitation of fish stocks, was it an attempt to establish or stabilize a central political authority or was it motivated by both? For what and by whom was that legal document used? And why was it kept? Hoffmann & Sonnlechner (2011) have demonstrated, based on the case of Habsburg emperor Maximilian I’s fishery patent from 1506, that such a close reading of historical documents is also indispensable for reconstructing past ecologies. Most of the written records discussed in this article were not produced to answer our research question, but out of very different reasons, reasons we need to understand when extracting data about fish.

Methodological approach
Sources were sought in libraries, federal, provincial and city archives as well as in archives of manors and monasteries keeping records relevant for the main study sites. Fishery sources – especially deeds of donation – exist at least since the 10th century, in some cases even earlier. Nonetheless, our search for sources started in the Late Middle Ages, a time for which we expected more specific information in terms of individual fish species and rivers. All types of written sources until the mid-20th century (and thus before first modern field sampling started at the study sites) were considered. In contrast to modern field samplings, which produce direct information about fish species, absolute abundance, population structure, etc., all historical records need further analyses and interpretations to obtain fish ecological information.

The classification of sources presented below uses the provenance and main topic of sources as a first criterion for differentiation, that is, we took sources’ producers and their objectives to record information about fish into account. Further criteria were the main fish ecological content and the possibility to gain quantitative or qualitative data on different temporal and spatial scales.

For each source type, main fish ecological parameters and other relevant information, as well as suggestions for their interpretation, are given. The most important objective of the source analysis was to verify whether data comparable with present fish ecological surveys can be gained. Thus, the focus was on the sources’ potential to reconstruct all occurring fish species (fish community, biodiversity) and the number (abundance) and weight (biomass) on a species level. Today, abundance and biomass are usually computed based on a standardised fishing effort that enables computing the total fish stock or a catch per unit effort depending on the river type (CEN 2003). Present surveys also investigate the population structure (length, weight, age, sex composition), but such parameters can rarely be gained from historical written records.

Results
Classification of written historical sources
Five main types of sources (early scientific fish ecological surveys, fishery, fish trading, fish consumption and cultural representation of fish) and 19 subtypes were distinguished and described in terms of origin, ecological information, temporal availability and spatial representativeness. The overview presented in Table 1 is based on the written documents that were explored for the case study rivers. Available information and knowledge from other case studies and rivers were added even if they were not used for the Austrian and Russian rivers subject to this study. Hence, the classification can be considered also as applicable to other rivers.

Early scientific fish ecological surveys were conducted by experts educated in (fish) biology and aimed at depicting the occurrence and sometimes abundance of all fish species in a river or in catchments and regions. Fish ecological surveys were
Table 1. Written historical sources to reconstruct fish communities and populations: main source types and subtypes distinguished. The table also summarises the main fish ecological parameters along with further ecologically relevant information as well as spatial and temporal scale and availability (see text for further details)

| Sources category                      | Sources type                                      | Main fish ecological content                                                                 | Other relevant content                                                                 | Comments on interpreting results                                                                 |
|---------------------------------------|--------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Early scientific fish ecological      | Historical species inventories (written and maps) | (all) Species occurring at a specific place                                                | –                                                                                       | Preparation of species lists and interpretation of information on abundance (e.g., classes) possible |
| surveys                               |                                                   | Commercial species (incl. stocked)                                                          | Verbal estimate of abundance                                                            |                                                                                                  |
|                                       |                                                   | Verbal estimate of abundance; yearly or average catch in figures                          |                                                                                       |                                                                                                  |
| Fisheries sources                     | Official surveys of commercial fish and fisheries | Commercial species (incl. stocked) (verbal) Estimate of abundance; yearly or average catch in figures | –                                                                                       | Commercial species can be assumed as abundant Interpretation of abundance (e.g., classes)     |
|                                        | Catch registers (commercial and recreational fishing) | Commercial species (incl. stocked)                                                         | Spatial description of fishing rights                                                    | Relationship between catch and abundance assumed If fishing effort known reconstruction of catch per unit effort possible for time series or periods |
|                                        |                                                   | Number of caught individuals/weight per species or total weight of catch                   |                                                                                       |                                                                                                  |
| Fisheries inventories of royal,      | Mostly commercial species not available for the case study rivers                          | Delineation of fishing districts                                                            |                                                                                       |                                                                                                  |
| monastic and aristocratic properties  |                                                   | Number of fishermen                                                                       |                                                                                       |                                                                                                  |
|                                        |                                                   | Fishing gear                                                                             |                                                                                       |                                                                                                  |
|                                        |                                                   | Fishing seasons                                                                          |                                                                                       |                                                                                                  |
| Fishing laws                          | Commercial species assumed as threatened          | Minimum weight or length/species                                                           |                                                                                       | Decline in abundance as a possible reason of restriction; Evaluation of minimum length/weight regulations |
|                                        |                                                   | Restrictions for fishing seasons                                                          |                                                                                       |                                                                                                  |
|                                        |                                                   | Areas of restricted fishing                                                               |                                                                                       |                                                                                                  |
|                                        |                                                   | Fishing gear                                                                             |                                                                                       |                                                                                                  |
| Tax and rent payment registers        | Commercial species                                | Money to be paid for right to fish                                                         |                                                                                       | Relation between taxes or rents and catch assumed; for rents, price indices to be taken into account |
|                                        |                                                   | Taxes for catch/year                                                                     |                                                                                       |                                                                                                  |
| fishermen guild documents             | Commercial species                                | Number of fishermen                                                                       |                                                                                       | Relation between number of fishermen and abundance Other relevant content informs about fishing effort and fishing pressure |
|                                        |                                                   | Delineation of fishing districts (species specific)                                       |                                                                                       |                                                                                                  |
|                                        |                                                   | Fishing gear                                                                             |                                                                                       |                                                                                                  |
|                                        |                                                   | Fishing gear                                                                             |                                                                                       |                                                                                                  |
| Judicial cases                        | Commercial species not used for the case study rivers |                                                                                           |                                                                                       | Intensity/pressure of fishing                                                                 |
|                                        |                                                   |                                                                                           |                                                                                       |                                                                                                  |
| Fish trading                          | Fish market sales lists, delivery registers,      | Sold species                                                                              |                                                                                       | Provenance of fish to be identified                                                                 |
|                                        | kitchen account books                             | Number of individuals or weight/species or total weight                                   |                                                                                       |                                                                                                  |
|                                        |                                                   |                                                                                           |                                                                                       | Relation between sale/demand and abundance                                                                 |
|                                        |                                                   |                                                                                           |                                                                                       | Customer demand, fish prices, transport means to be considered                                                                         |
| Fish trading laws                     | Fish (market) prices                              | Sold species                                                                              | Area of delivery (local & imported)                                                     | Information about provenance of fish species appearing in market or delivery registers         |
|                                        |                                                   |                                                                                           |                                                                                       |                                                                                                  |
| Fish consumption                      | Cook books                                       | Consumed fish                                                                             | Price per unit of species                                                               | Relationship between resource availability and prices Development of price indices, customer demand to be considered |
|                                        | Restaurant menus                                 |                                                                                           |                                                                                       |                                                                                                  |
|                                        | Pictures (paintings, engravings)                  | Commercial fish                                                                           |                                                                                       |                                                                                                  |
mostly prepared as written species inventories, but since the second half of the 19th century also as fish distribution maps. Precursor studies of this source type exist since the antiquity (e.g., Pliny). In the 13th century, scholars such as Hildegard von Bingen and Albertus Magnus charted the specifics of several European freshwater fish (see e.g., Hoffmann 1996, 2000); the 16th century was particularly productive for fish biological literature (e.g., Belon 1553; Gesner 1558; Rondelet 1558; Mangolt 1557). Such writings could be valuable depending on the region of interest. In particular, the use of medieval and early modern sources, however, may require the help of specialists to ensure a sound interpretation. The use of original versions is recommended because translations were often unreliable. For our study sites, more detailed early scientific surveys are available since the late 18th century (Marsigli 1726; Meidinger 1785–1794; Lepekhin 1805). Until the late 18th century, species inventories only exceptionally referred to the occurrence of fish in precise rivers or river sections. The number and quality of the surveys improved over the years in terms of completeness of the fish community and also in terms of spatial information. As Siebold (1863) or Wittmack (1875) explain in detail, early scientific inventories were usually compiled based on systematic or selective enquiries of fishermen and fishmongers. The fish distribution map of Salzburg (Kollmann 1898), described in further detail below, is based on such data. In an optimal case, the studies deliver the total fish community of a river or river section for a given period and abundance in verbal form, for example, that a species is dominant, rare or frequent in a section. Such information can be transferred into abundance classes. Nonetheless, the compilation of fish communities is often hampered

Table 1 (continued)

| Sources category | Sources type | Main fish ecological content | Other relevant content | Comments on interpreting results |
|------------------|--------------|-----------------------------|-----------------------|---------------------------------|
| Fish in culture  | Folk tales   | Commercial fish not used for the case study rivers | Indication of common or valuable species |
|                  | Family names | Commercial and culturally important fish species | Indication of common or valuable species |
|                  | Place names  | Commercial and culturally important fish species | Indication of abundant and commercially significant species when relation to fish species and local origin of the name can be proved |
|                  | Emblems      | Commercial fish species (occurrence; high abundance) | Indication of abundant and commercially significant species | Relation between species in emblems and abundance |

Spatial and temporal characteristics – only main sources used for the Austrian and Russian study sites considered

| Sources category                          | Sources type                                           | Spatial unit                      | Temporal unit                      | Temporal availability for the study sites |
|-------------------------------------------|--------------------------------------------------------|-----------------------------------|------------------------------------|--------------------------------------------|
| Early scientific fish ecological surveys  | Historical species inventories (written and maps)     | Usually longer river sections; sometimes specific places | Usually period of one to several decades | Since late 18th century                     |
| Fisheries sources                         | Official surveys of commercial fish and fisheries     | Usually longer river section (sometimes for fishing districts) | Usually period of one to several decades | Since late 18th century                     |
|                                            | Catch registers (commercial and recreational fishing)  | Usually specific fishing district | Precise years, months, weeks or days, | Not for the study sites; since 17th century for other European rivers |
|                                            | Fishing district descriptions                         | Specific fishing districts/river sections | Varies but usually specific years or period of several decades | Since 15th century |
|                                            | Fishing laws                                           | Varies from specific section (medieval/early modern) to provinces for early modern to present time | Period of several years around issuing period | Since late middle ages, that is, 13th century |
|                                            | Tax and rent payment registers                         | Fishing district                  | Precise years                       | Since 18th century |
|                                            | Fishermen guild documents                              | Fishing district                  | Precise years to periods of several years | Since 17th century |
|                                            | Fish market sales lists, delivery registers, kitchen account books | Varies depending on area of origin of fishmongers/traders | Precise years, months, weeks or days, | Since 14th century |
|                                            | Fish trading laws                                      | Administrative units (town, regions) | Period of several years around issuing period | Since 14th century |
|                                            | Fish (market) prices                                   | Administrative units (town, regions) | Period of several years around issuing period | Since 14th/15th century |
because early scientific surveys used different taxonomies and systematics.

**Fishery** provides the largest amount of written records. We divided this type into six subtypes:

- **Official surveys of commercial fish and fisheries** are statistics commissioned by the state to gain an overview about the status of fishery. They can be often complemented by a wealth of contemporary articles published in fishery journals. Official surveys appear as a source type in the second half of the 19th century, when official statistics in general became more common (Österreichisches Statistisches Zentralamt 1979). The first Austrian fishery statistic was published in 1874 (Kraft 1874). It covered the Austro-Hungarian Monarchy, but official surveys can also be related to particular provinces. In the Russian North, the official surveys started in the same period (Lajus et al. 2007a). This source type provides details about commercial fish, their yearly or average catch, but also about fishery as such (main fishing areas, numbers of fishing districts, numbers of persons engaged in fishery, fish farming, etc.). Abundances are sometimes mentioned in verbal form.

- **Catch registers** are produced by fishermen. They inform about exploited fish, the weight or number per species, and they are related to precise days, sometimes months or years, and to specific river sections. When assuming a relation between catch and actual abundance, catch registers are the most valuable type of historical sources to reconstruct historical fish population changes. If the fishing effort is known (type of fishing gear, number and size of nets, duration of fishing, number of fishermen), then catch registers even enable computing an approximate catch per unit effort. The availability of this source type apparently depends on the organisation of the respective fishery. Catch registers are especially available when fishing required expensive gear (e.g., salmon fishery in Russia) or when large manors or monasteries carried out fishing themselves and did not lease their fishing rights to external fishermen who then paid rents and/or had to deliver fish to their landlords. The latter was the case in the Austrian study sites, for which we therefore have no catch registers. For other Austrian rivers, catch registers are available since the 17th century (e.g., from the St. Paul monastery for the Lavant, from Seckau monastery for the Mur or from Lambach monastery for the Traun).

- **Fish inventories of royal, imperial, monastic or aristocratic properties** contain details about species occurring in rivers belonging to these properties. This type of source was not used in the present study, but we assume that they mostly considered commercially exploited fish.

- **Fishing district descriptions** comprise a large variety of anecdotal sources prepared by fishermen, fishing right owners or administrative institutions. Such sources were recorded and kept for the study sites since the late 16th century. They inform about commercial species, average catch values, stocking, special threats to particular species and use of fishing gear. Thus, they provide potentially similar evidence as catch registers, but with a lower spatial or temporal resolution. While time series on a yearly level help reconstruct year-to-year variations, the interpretation of average data for a longer period has advantages because they reflect long-term variations. Fishing district descriptions sometimes also report the fishing effort, which might be necessary for investigating catch registers.

- **Fishing laws** exist for the Austrian study sites since the late 14th century, although they are mainly local by-laws until the early 16th century. They regulate minimum length or weight of specific species, closed seasons and forbid or allowed certain gears; later, they also restrict fishing places. Based on fish species mentioned in laws, one may draw cautious conclusions about overexploitation and decreasing stocks. Minimum length or weight regulations allow assumptions about whether stocks were managed sustainably or not, considering present knowledge about minimum sizes to reach adult life stages. Clearly, such presumptions do not take into account the potential neglect of minimum size regulations.

- **Tax and rent payment registers** are prepared by fishermen or administrative authorities and are available for Russian sites since the 17th century (tax records) and since the 19th century for the Austrian Danube (rent records). They inform about the average or yearly tax to be paid by a group of fishermen or about the rent for a leased right to fish in a river section. A direct relation between tax and catch can be assumed under the assumption that the recorded values were reported correctly. Taxes were related either to the total catch or to particular species. More complex is the interpretation of rents to be paid, because they were influenced by various factors (e.g., markets, price indices). Nonetheless, in professional fisheries, one can estimate that rents were positively correlated with the potential catch and thus actual abundance.

- **Guild documents** were recorded by fishermen and comprise a great variety of sources. For the Viennese Danube fishermen, such documents were kept since the 16th century, but other European examples date back 200–300 years earlier. The latter sometimes provide details about species-specific fishing gear (Hoffmann 2000). Valuable information relevant from an ecological viewpoint is for instance the number of fishermen. An increase in fishermen was likely followed by rising pressure, which – with a time lag – might result in a decrease in fish stocks.
Overexploitation, however, depends on the potential yield, and additional sources and proofs are needed for such interpretations. A decrease in fishermen can point to overexploitation and declining fish stocks; this relation was assumed to explain the reduction in fishermen along the Salzach during the 17th century (Freudlsperger 1936). Note, however, that other underlying economic factors, such as a shift of fishermen to more beneficial professions, may be at work.

Summarising the contents of fishery management sources, one can state that the first four, in some cases five, subtypes inform directly about commercial species. They often provide details about stocking of native and non-native species. Catch registers and sometimes also fishing district descriptions present quantitative catch information for particular river sections, either per year (catch registers) or as averages within a certain period (fishing district descriptions), and can thus reflect a direct relation to abundance. Official surveys mostly contain quantitative or verbal abundance of species on a regional or national level. Tax and rent registers also give quantities, but especially, rent registers cannot be directly related to specific fish species or actual abundance in local rivers. Such registers require further analyses, which in most cases involve incorporating economic aspects other than fish.

A type of fishery source we did not use for our study is judicial cases, although they might offer valuable details about occurring fish species, their abundance and in particular also information to estimate the degree of fish exploitation not recorded in the other sources.

Fish trading sources such as market sale registers, delivery records (e.g., fish sold to a particular monastery) and kitchen account books were often recorded as serial quantitative information. Kitchen account books are available for the Klosterneuburg monastery since the 14th century (Fritsch 2008), delivery records mainly since the 17th century and market statistics since the late 18th century (Viennese fish trader guild). These sources usually contain the number of individuals or total weight per species. Sometimes, both the numbers and total weights are available, enabling an estimate of the average weight of individual fish. Usually the data are related to years, sometimes also to months, weeks or even days. Delivery and fish market sale registers can be analysed in a similar way as catch data, that is, they can inform directly about an increase or decrease in the stocks of the mentioned fish species. Additional information, however, is necessary. In particular, the provenance of fish has to be known to distinguish between supply from local waters, imported and farmed fish. It is further necessary to roughly estimate the proportion of local species and whether this proportion was stable or whether exports and local sales varied between years. This proportion can also differ between single species. Although a local shortage can be concluded when fish from distant rivers were traded, it is usually difficult to determine a ratio between local and nonlocal fish with hindsight. ‘Was the local shortage caused by a demand exceeding potential yields, by climatic influences or by human impacts on fish?’ This must be investigated based on additional sources providing information on such different drivers. Finally, the fishing effort has to be known (see above, catch registers). Details about the provenance of fish can often be found in fish trading laws and regulations, as, for example, in documents for the Viennese fish trader guild. Together with anecdotal fishery sources, trading laws help distinguish between local species and those imported from nonlocal rivers.

Fish prices are a common and often available source type. Nonetheless, linking them to the local abundance of fish is a complex task. Lacking in-depth research that integrates expertise in the history of prices and the factors influencing them, no precise method to relate price to local abundance can be provided here. Rather, we suggest in a first step to employ fish prices mainly to support hypotheses about frequent, mass or rare and thus valuable fish (Lajus et al. 2001), that is, the cheaper a fish, the higher its abundance. This, however, is not always the case. Prices for cyprinids from the Danube, for example, remained low compared with other species even when they had become rarer in the late 19th and 20th centuries. Cultural preferences for specific species are merely one distortive factor influencing prices.

Fish trading sources also provide insights into the economic importance of and customer demand for fish. Although this aspect is not dealt with here in detail, it is an important factor when investigating interactions between rivers and societies.

Fish consumption sources comprise cook books and restaurant menus but also menus of elite or monastic households. There is no direct relation with the abundance of fish in a specific local river, but both source types can support findings about the local occurrence of fish species. Furthermore, they provide valuable details about the preferences of social groups and, in the case of restaurant menus, about the prices and values of fish (Jones 2008). Although we focus here on written documents, note that the most important source for fish consumption is archaeozoological records. The ‘Fish Remains Working Group’ releases proceedings of its biennial meetings, and monographs or compilations for specific regions exist as well (e.g., Hüster-Plogmann 2006). Recently, Van Neer & Eryvynck (2010) explored the possibilities and shortcomings of
combining written documents and material fish remains for reconstructing baseline conditions.

Cultural representations of fish, for example, in pictures, folk tales, place and family names or emblems, indicate a frequent local occurrence of particular fish species. For instance, in Russia, family names originated only from freshwater fish such as perch, pike, pikeperch Sander lucioperca, crucian carp Carassius carassius, carp Cyprinus carpio, wels Silurus glanis and ruffe (for instance, Okunev, Sudakov, Karasev, Karpov, Somov, Yershov). Given that the spatial origin of these family names is known, cautious conclusions can be drawn about the former distribution of fish. The absence of old Russian family names referring to marine fish might indicate that people did not know marine fish before the 18th to late 19th century, when such family names massively appeared. The emblem of the town of Narva in the 14th and 15th centuries contained sturgeon and clearly proved, in connection with other sources, that they were abundant enough for fishery in this area.

Particular fish species are represented in pictures, especially when they are valuable and rare. Species tend to be depicted more based on their peculiarity than on their abundance. One example is the painting of a beluga sturgeon Huso huso caught in the Salzach in 1617 (Waidbacher & Haidvogl 1997). Although catches of beluga sturgeons in the Austrian Danube section were already very scarce in the 19th century, stories about their abundance in previous centuries were still lively, as, for example, described in travel-ogues.

For the fish ecological interpretation of the historical records described above, several common characteristics exist.

Recorded fish names and species identification

A prerequisite for an ecological interpretation is the possibility to link the mentioned fish names to a particular species. Species identification is problematic in many sources, often even in early scientific surveys. One reason is the changing systematics and taxonomy of fish species (see Kottelat 1997 for details). Many of the 19th century fish biologists identified new species based on morphological characteristics. Sometimes these species were later considered to be merely a local form of another species. Such incorrectly defined species can be identified with hindsight when reference specimens are available in museums. Kottelat (1997) is a most valuable reference for such cases. If no specimen exists and the morphological description is imprecise, then it can prove difficult to identify the species. Furthermore, some species were scientifically described only in the 20th century; examples are the whitefin gudgeon, which was described as Gobio albipinnatus by Lukasch 1933 (recently defined as Danube whitefin gudgeon Romanogobio vladykovi, Kottelat & Freyhof 2007), or the Balon’s ruffe Gymnocephalus baloni, described by Holcik and Hensel in 1974. This deficit continues to grow with the genetically based identification of new species.

A similar difficulty applies for the use of vernacular names in fishery and fish trading sources. While the names of species showing specific morphological characteristics (e.g., Danube salmon Hucho hucho or salmon, pike, pike perch, wels) can be trusted, this does not hold true for unremarkable species. Vernacular names can show both synonyms (different names for the same species in different regions) and homonyms (one name for different species in different regions). In Austria, the name ‘Schied’, for example, usually refers to Aspius aspius, but in Salzburg also to Leuciscus leuciscus (e.g., Heckel 1854). Chondrostoma nasus in many Austrian regions was named ‘Nase’, in others ‘Weißfisch’ (Raab 1978) or ‘Bratfisch’ (Kraft 1874). ‘Weißfisch’ refers at the same time to cyprinid fish in general – or in Lower Austria to Alburnus alburnus (Hütter 1874). ‘Bratfisch’ was used in Moravia for Squalius cephalus (Jitteles 1863/64). Russian sources from the 15th century mention fish named ‘lokhi’, which can mean either Atlantic salmon or brown trout, and it is nearly impossible to sort out the correct species without additional information. Tonny Fenne’s dictionary lists, among other fish traded at the market of Pskov, ‘kitt-tyba’, which means ‘whale fish’ in direct translation from Russian. It is highly unlikely that it really refers to whale, but rather to some local fish species.

Considering that fish biologists often relied on questionnaires, it is likely that fishermen sometimes responded erroneously and that species inventories compiled based on such sources are therefore incorrect. A careful evaluation, especially of fish that may have been easily confused, is necessary. This requires compiling and interpreting all sources available.

Absence of species

Although early scientific surveys aimed at recording all fish species, it is well known that even these sources do not always reflect the complete actual situation. This is because small, unremarkable species are disregarded. The interrogation of fishermen or traders may result in an over-representation of larger, economically valuable or peculiar species such as the European bittering (Rhodeus amarus), which was already described in late medieval sources because of its particular spawning habits (Van Damme et al. 2007). Small, inconspicuous fish – in European rivers often cyprinids – are thus often missing. Apart from
the neglect of some species, the late scientific description of others may result in the absence of species in historical fish inventories.

Because early scientific fish inventories can be incomplete, it is difficult to determine the actual absence of species. Only sometimes sources explicitly mention that a specific species did not occur. In rare cases, missing mentions can indicate absence or a very low abundance of a species when the species are listed in earlier and/or later sources. The Kandalaksha State Reserve, for example, has kept annual records on natural phenomena in its lands and waters since 1952. The three-spined stickleback *Gasterosteus aculeatus* is recorded there for the White Sea with verbal abundance indications in all the years except from 1967–1974 and 1978–1996 (Lajus et al. 2013). It requires longer time series to be able to assume that stickleback abundance in these periods was extremely low, otherwise it would have been mentioned.

**Ecological interpretation of sources**

As indicated in Table 1, the different sources contribute to several fish ecological parameters. Early scientific and fishery surveys are certainly the main source for species inventories as complete as possible, and they provide details about abundance classes. Catch registers or fish market records can help reconstruct absolute abundance information if details about fishing area and intensity are available. Even if this is impossible, declining supply and especially catch data for single species can indicate decreasing populations because of habitat change or overexploitation. Other sources such as fishing or fish trading laws support the interpretation and investigation of catch and fish market registers and can also show the intensity of fishing pressure.

The different types of historical sources can be merged into single data sets considering basic fish ecological parameters such as: (i) species presence, (ii) relative abundance/abundance classes and (iii) absolute abundance information. While the first two often enable considering the total or at least large parts of the fish community, the third parameter is usually computable for selected (commercial) species only. Such combined data sets can support the systematic investigation of fish species not mentioned in all sources or indicate a change in dominant or rare species. As was shown for the Salzach, species can be missing due to incomplete sources or reflect real biological conditions. The identification of the latter requires further knowledge and investigation of possible reasons. These can include overexploitation of a particular species as well as a habitat change because of weirs, pollution, channelization or climate change.

When investigating fisheries catch or market data, an increase or decrease can also indicate changing societal preferences. Combined data sets enable the comparison of historical sources from different regions and countries.

**Selected examples for the case study sites**

**Early scientific and statistical surveys: changes in Salzach fish communities**

The use of early scientific and statistical surveys is discussed by comparing the present fish community of the Salzach River (samplings 1992–1994 and 2006–2008) with those around 1900, 1850 and 1796. Present data stem from field monitoring, distributed over the whole river. For 1900, a fisheries map from 1898 and a fisheries survey from 1904 were used (Kollmann 1898; Salzburger Fischereikataster 1904). Two journal articles from 1854 (Heckel 1854) and 1859 (Zetter 1859) reflect the situation of the mid-19th century. The oldest known compilation of fish inhabiting the rivers of Salzburg was published by the naturalist Hübner (1796). Among the different authors were fish biologists (Heckel) and fishery experts (Zetter, Kollmann). Hübner was probably the one with the least fish biological knowledge. The sources from 1859 and 1796 provide information for the whole federal state of Salzburg, but one can assume that (apart from species migrating from lakes) all occurred in the Salzach. For most of the species, the determination was certain (e.g., trout, grayling *Thymallus thymallus*, wels, pike), but for some, the vernacular and even scientific names did not allow a definitive allocation. This refers, for example, to the details Heckel (1854) and Zetter (1859) provided for various Gobiidae, which prompted us to consider *Gobio* spp. only on a genus level. Also for Leuciscidae, several species were differentiated, but only the presence of dace *Leuciscus leuciscus* was certain, and other mentions had to be ignored.

The total number of species recorded varied for the different points in time (Table 2). This variability only partly reflects ecological conditions, but more the incompleteness of the sources. Only the species lists of Heckel (1854) and Zetter (1859) can be assumed to be complete or close to complete and are thus sufficient for a direct comparison with the present situation. Among the 24 species found in recent years, five were introduced since the late 19th century. *Oncorhynchus mykiss* and *Salvelinus fontinalis* are widespread today and frequent to dominating, especially in tributaries. *Ctenopharyngodon idella*, *Pseudorasbora parva* and *G. aculeatus* have been detected in low densities (Schmall & Ratschan 2011). Of the 19 native species caught in past years, all except *Coregonus* spp. have been reported in Heckel...
(1854)/Zetter (1859). Thirteen species, however, disappeared from the river in the 20th century, most probably due to human modifications such as energy production, channelization and flood protection. Other impacts such as pollution are less pronounced.

What can be concluded about changes in the 19th century? Hübnern (1796) took into account only the most common and commercial species. Rare species (Alburnoides bipunctatus or Leuciscus souffia) or migrants from lakes (S. trutta or Coregonidae) are missing. He also does not mention the stone loach (Barbatula barbatula) or the carp. Prima facie, this might be due to a misinterpretation of the vernacular names ‘Grundel’ (normally B. barbatula) and ‘Gründling’ (normally Gobio gobio) when Hübnern reports the presence of ‘Grundel, Gründling, Cyprinus gobio’. The common carp was, however, rarely confused with other species. We therefore assume that this species was very rare, if not absent, at the end of the 18th century. The carp is also reported in Kollmann (1898) only for the lowest section downstream of the city Salzburg, making it difficult to determine whether the presence and abundance changed in the 19th century.

The absence of wels or sterlet Acipenser ruthenus in Kollmann’s map might be due to their low abundance and catch, but it is remarkable that commercially exploited fish such as crucian carp are also not mentioned. Around 1900, the Salzach was already channelized in some sections, and floodplain waters as typical habitat of the crucian carp were disconnected. Accordingly, the fish inventories may already indicate a change in the fish community. In Kollmann’s map, species with no commercial value (e.g., A. bipunctatus, Gobio sp.) were clearly ignored and some species had a smaller distribution, such as roach or carp. These observations have to be further explored by considering (water) temperature changes.

As Kollmann provided his results based on six distinct river sections, we can compare the distribution of fish species with the present situation. In particular, nase and barbel Barbus barbus (as typical fish of the middle and lower river section) as well as inhabitants of floodplain waters (pike) and small species such as stone loach and common minnow Phoxinus phoxinus currently occur in fewer segments and thus show a far smaller distribution than in 1898 (Table 2, two columns on the right).

Catch records and tax registers: Atlantic salmon fishery in the Russian North, 17–18th centuries

This case study employs tax records to describe the catch of Atlantic salmon in the Russian North during the 17–18th centuries (Lajus et al. 2001, 2005, 2007a; Alekseeva & Lajus 2011). The use of historical sources for studying Atlantic salmon population dynamics in northern Russia is facilitated by several factors: (i) catches of salmon were registered quite accurately because this fish was one of the most important goods and subject to taxation; (ii) salmon fisheries were very important for the local economy, and the number of fishermen was therefore only minimally affected much from year to year by competing commercial activities; and (iii) there were only minor changes in fishing methods over centuries, and fishing effort was quite stable across years.

Tax information was found in archives of the central government and in large monasteries. Governmental departments were responsible for collecting taxes, and the most common fisheries duty on salmon areas was the ‘tenth fish’, that is, the tax equalled 10% of the total annual catch. As salmon fisheries constituted a significant part of the monasteries’ income, catches were carefully recorded. The privileges for salmon fisheries were quite complicated and varied spatially and temporarily. Thus, the reconstruction of the time series required good knowledge of the historical and geographical context.

The organisation of the salmon fisheries was similar at least from the 16th up to the mid-20th century and based mostly on weirs partly or completely blocking the river. These arrangements were constructed of stakes and branches with inserted net traps. Fishermen controlled the integrity of the weirs. For example, upstream of the big Chebot weir (Vyg River) in the 18th century, smaller weirs were erected to monitor potential damage to the large weir: when fish reached the smaller weirs, it was evident that the main weir downstream was broken (Lajus et al. 2007a).

The operation of the weirs indicated no concern of fishermen to allow sufficient individuals to migrate to the spawning grounds upstream. This, however, did not result in the disappearance or even notable decline in salmon populations. Salmon were able to pass weirs when the water level rose due to precipitation in summer or in autumn, or when weirs had been destroyed by floating ice in late autumn. Spawners that escaped were able to maintain a sustainable population because the main limitation for the population was not the number of spawners but the availability of areas suitable for growing juveniles.

Assuming a constant fishing effort, catch size reflected salmon abundance. We pooled data from four different locations and obtained a single time series containing 51 values representing the size of the salmon catch in the Russian North from 1615 to 1772 (see Table S1).

Correlating this time series with temperature series available for that period reveals a statistically significant positive correlation ($r = +0.556, P < 0.05$),
whereas population declines tended to coincide with colder periods. This suggests that in the 17th and 18th centuries, salmon abundance in the Russian North was affected by climate (see Lajus et al. 2005, 2007a for further analysis for the 19th and 20th centuries). Herring catches showed no such correlation, probably because catch size depended not only on population size but also largely on the variation of fishing effort (Lajus et al. 2007b).

Fishery and fish trading sources: the Viennese Danube

In the Austrian Danube, four diadromous sturgeon species occurred until the late 19th and early 20th century: beluga, stellate sturgeon Acipenser stellatus, Russian sturgeon Acipenser gueldenstadi and ship sturgeon Acipenser nuidiventris (Bloesch et al. 2006). For the latter two, landlocked populations exist. Local by-laws from the 14th and 15th centuries indicate that beluga, Russian and ship sturgeons were caught regularly in the Viennese and Lower Austrian Danube (Winter 1886). Remarkably, the ordinances of the 16th century and later did not consider Danube sturgeons. As fishing pressure increased in the 16th century downstream in the Hungarian Danube, the absence of the laws might point to a near extinction in the Austrian river section (Balon 1968). Nonetheless, another potential explanation is that these migratory species were considered differently than resident species, which spend their whole life cycles in the local waters (Hoffmann & Sonnlechner 2011; Haidvogl et al. in press). In the early 18th century, Danube sturgeons were still abundant at the Viennese fish market. Mostly they were traded from the Hungarian Danube as stated, for example, in the law of 1716 regulating fish trade in Vienna (WSLA Karl VI

Table 2. Fish species occurring in the Salzach River in 1796, 1854/1859, 1888/1904 and at the present time (order of species according to the frequency of mentions in the sources); two columns on the right: species occurrence in river segments delineated based on morphological conditions

| Species name                      | Hubner 1796; | Heckel 1854; Zetter 1859; | Kollmann 1898; fisheries survey 1904 | Present field sampling | Number of segments - Kollmann | Number of segments present time | Number of segments disappeared |
|-----------------------------------|--------------|---------------------------|--------------------------------------|------------------------|-------------------------------|-------------------------------|-------------------------------|
| Hucho hucho                       | 1            | 1                         | 1                                    | 1                      | 4                             | 3                             | 1                             |
| Salmo trutta tario                | 1            | 1                         | 1                                    | 1                      | 6                             | 6                             | 0                             |
| Thymallus thymallus              | 1            | 1                         | 1                                    | 1                      | 5                             | 6                             | -1                            |
| Esox lucius                       | 1            | 1                         | 1                                    | 1                      | 6                             | 2                             | 4                             |
| Barbus barbus                     | 1            | 1                         | 1                                    | 1                      | 5                             | 1                             | 4                             |
| Chondrostoma nasus               | 1            | 1                         | 1                                    | 1                      | 5                             | 3                             | 2                             |
| Phoxinus phoxinus                 | 1            | 1                         | 1                                    | 1                      | 6                             | 3                             | 3                             |
| Rutilus rutilus                   | 1            | 1                         | 1                                    | 1                      | 1                             | 3                             | -2                            |
| Squalus cephalus                  | 1            | 1                         | 1                                    | 1                      | 5                             | 2                             | 3                             |
| Lota lota                         | 1            | 1                         | 1                                    | 1                      | 2                             | 1                             | 1                             |
| Perca fluviatilis                 | 1            | 1                         | 1                                    | 1                      | 1                             | 1                             | 0                             |
| Cottus gobio                      | 1            | 1                         | 1                                    | 1                      | 6                             | 5                             | 1                             |
| Cyprinus carpio                   | 1            | 1                         | 1                                    | 1                      | 1                             | 2                             | -1                            |
| Barbatula barbatula               | 1            | 1                         | 1                                    | 1                      | 2                             | 1                             | 3                             |
| Alburnus alburnus                 | 1            | 1                         | 1                                    | 1                      | 2                             | 2                             | 0                             |
| Gobio sp.                         | 1            | 1                         | 1                                    | 1                      | 0                             | 1                             | -1                            |
| Salvelinus umbla                  | 1            | 1                         | 1                                    | 1                      | 0                             | 2                             | -2                            |
| Salmo trutta lacustris            | 1            | 1                         | 1                                    | 1                      | 1                             | 2                             | 2                             |
| Alburnoides bipunctatus           | 1            | 1                         | 1                                    | 1                      | 1                             | 0                             | 1                             |
| Eudontomyzon mariae              | 1            | 1                         | 1                                    | 1                      | 2                             | 0                             | 2                             |
| Tinca tinca                      | 1            | 1                         | 1                                    | 1                      | 1                             | 0                             | 1                             |
| Abramis brama                    | 1            | 1                         | 1                                    | 1                      | 3                             | 0                             | 3                             |
| Leuciscus leuciscus              | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 1                             |
| Rutilus rutilus                  | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 2                             |
| Coregonus sp.                     | 1            | 1                         | 1                                    | 1                      | 1                             | 0                             | 1                             |
| Acipenser ruthenus                | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Carassius carassius              | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Leuciscus souffia                 | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Scardinius erythropthalmus        | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Silurus glanis                    | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Zingel streber                    | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Zingel zingel                     | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Onchorhyncus mykiss (introduced)  | 1            | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Salvelinus fontinals (introduced) | 1            | 1                         | 1                                    | 1                      | 0                             | 6                             | -6                            |
| Ctenopharyngodon idella (introduced) | 1          | 1                         | 1                                    | 1                      | 0                             | 0                             | 0                             |
| Pseudoraspora parva (introduced)  | 1            | 1                         | 1                                    | 1                      | 0                             | 1                             | -1                            |
| Gasterosteus aculeatus (introduced) | 1           | 1                         | 1                                    | 1                      | 0                             | 1                             | -1                            |
| Total number                      | 18           | 30                        | 21                                   | 24                     | 24                            | 24                            | 24                            |
| Introduced                        | 0            | 0                         | 0                                    | 0                      | 5                             | 5                             | 5                             |
1716). Following massive overexploitation in the middle and lower Danube, sturgeon deliveries to Vienna started to decrease at the early 19th century (Fitzinger & Heckel 1835; Balon 1968; WSLA Fischkäufler). For the Danube, fishing laws and fish trading sources clearly prove the sturgeons’ almost extirpation in Austria at the latest by the 18th century. Overexploitation was very probably the main driving force.

Although the amounts of fish listed in the delivery records of the Klosterneuburg monastery cannot be related directly to catches in the Viennese Danube, the ten registers available for the period 1721–1815 allow assumptions about the exploitation and abundance of some fish species during that period. No Danube sturgeons were sold to the monastery in 1814 and 1815. One interpretation is that this reflects the low quantities available for fish traders in particular in these 2 years. Remarkably, the amounts of wels increased considerably from a few kilograms in 1721 and 1722 to several 100 k in 1814 and 1815. Perhaps wels compensated for the declining sturgeon supplies, which are also visible in the registers. In 1721, 1722 and 1729, only 85 kg of a total of 9000 kg carp was native Danube carps; all others were farmed fish (StA Klosterneuburg 1721–1815). In 1814 and 1815, no Danube carps were delivered to the monastery, although it has to be noted here that the delivery records for these 2 years are incomplete. The low abundance of wild carp in the last decades of the 18th century – a species which can be assumed to have occurred frequently in the Viennese Danube – is, however, also mentioned by Meidinger (1785–1794). The reasons for this decline are not yet fully investigated. Apart from overexploitation, the particularly high hydromorphological dynamics of the Danube in the last decades of the 18th and early 19th century may have played a role (Pišút 2002, 2008; Hohensinner et al. 2013).

A decrease in abundance of certain commercial species can be estimated based on fishing laws. Up until the 20th century, the limited knowledge about fish growth and reproduction often resulted in inadequate minimum length or weight regulations. Hence, juveniles could have been caught, even legally, in large quantities and the populations might have dropped steadily. A fishing law enacted by Empress Maria Theresia in 1771 specified minimum weight regulations for the main Danube fish. For species termed as ‘small’ in the sources (tench, Tinca tinca, perch, burbot, zingel, Zingel zingel), the minimum weight was 0.14 kg, whereas for large ones (carp, pike, pike perch, Danube Salmon), the minimum weight was 0.42 kg. Transferring weight into length (regressions from fishbase.org and internal data from the EFI + project) and comparing with today’s limits clearly show that the limit for pike and in particular for Danube salmon and burbot was far too low: it did not prevent fishing of juveniles and thus overexploitation and decrease in fish stocks. The opposite, that is, very high minimum length, was in force for species such as the zingel (fishing law Maria Theresia 21.3.1771, published in Kropatschek 1787; Table 3).

### Discussion

We identified a large variety of written historical sources that support the investigation of the historical dynamics of fish communities and populations. We considered all kinds of records containing potential fish ecological information. Some source types that comprise only marginally relevant details were not described in detail in the classification scheme (e.g., judicial cases on poaching or disputed fishing rights).

The potential fish ecological contents of these sources and their interpretation depend first and foremost on the producers and their interests. We therefore took this as the first criterion for the classification scheme. While early scientific surveys aimed at describing the total fish community of a river or river section, all other source types focus on commercial species. A critical evaluation of sources, referred to as ‘sources critique’ by historians, is indispensable for their correct analysis. For example, fish catch or fish market information may be lower than in reality to avoid taxes. Also, as outlined by the ‘shifting baseline syndrome’, the experience of the observer in terms of previous fish abundance has to be taken into account. Thus, a ‘low abundance’ after a phase of ‘high abundance’ in one period may be nevertheless higher than a ‘high abundance’ after a period of ‘low abundance’ (Pinnegar & Engelhard 2008; Fortibuoni et al. 2010). Certainly, the analysis of some sources will require more comprehensive investigations in the future to establish relations between the sources’ information and the actual presence or abundance of fish. A case in point is the interpretation of historical fish prices.

| Table 3. Minimum size regulations in the fishing laws from 1771 and 2002 (length in cm) |
|---------------------------------|----------------|----------------|-----------|
|                                 | Archduchy Austria | Lower Austria 2002 | Difference |
| Hucho hucho                     | 35              | 75              | –40       |
| Esox lucius                     | 40              | 50              | –10       |
| Lota lota                       | 26              | 35              | –9        |
| Cyprinus carpio                 | 32              | 35              | –3        |
| Tinca tinca                     | 23              | 25              | –2        |
| Sander lucioperca               | 37              | 35              | 2         |
| Zingel zingel                   | 27              | 20              | 7         |
| Perca fluviatilis               | 22              |                |           |
The classification suggested in this article was based on sources found for the Viennese Danube, the Salzach and rivers in the Russian North. Importantly, the records do not merely reflect local conditions. They were produced within a larger framework of scientific development, fisheries economy and consolidating administrations prevailing in most European countries. For early scientific surveys and precursor studies, some examples for European countries were given above, but numerous other studies could be mentioned, among them the works of Bloch (1782–1784) for Germany or Cuvier & Valenciennes (1828–1849) for France. Some fishery sources emerged from the administration of large manors and monasteries; these sources look similar in most European states despite differences in terms of organisation.

Nonetheless, dissimilarities need to be considered when studying river systems in other countries. For example, even the temporal availability of sources differed for the study sites presented here. Fishermen guild documents have been kept for Vienna since the 16th century, a time when similar organisations in the Russian North did not exist. For Burgundy, Beck (2008) demonstrated the preparation of fishing district descriptions as far back as the late 14th century. Hoffmann (1996) refers to fishing laws enacted in Italy or France already in the Late Middle Ages. Clearly, the availability of sources is also influenced by their keeping. Many archives were destroyed during wars, and sources were often discarded on purpose.

The source types produced also depend on the occurring species, which in turn influence specific forms of fishery. In the Russian North, diadromous salmons were valuable commercial species. Their catch required considerable organisational and financial efforts for fishing gear and transportation. Accordingly, written documents about the catches and taxes were produced. In contrast, much fewer catch records were kept from the small-scale professional fisheries that prevailed in Austrian rivers inhabited by freshwater fish. Since the Late Middle Ages, fisheries were carried out by single persons or small groups of professionals. Catch registers exist only when monasteries or large manors did not lease their fishing rights to private fishermen. The general observation therefore is that the existence of many types of sources depends on some form of a larger social organisation to exploit the fish resource.

Moreover, specific political conditions can result in further subtypes that have not been considered here. Beslagic et al. (in press) investigated fish ecological changes in the Seine based on early scientific surveys from the 18th and 19th centuries. These were prepared upon order by the king as the central authority and were accomplished by civil engineers rather than biologists. Such sources might be considered as a subtype of early (fish) biological surveys, which were not available for the study sites.

The examples of the Salzach, the Danube and northern Russian rivers demonstrated that all historical sources, including early scientific surveys, require additional processing and well-grounded assumptions to extract reliable fish ecological information. The information involves different levels of uncertainty in terms of when, where and how the data were collected, the completeness and the proportion of a local fish community or fish population recorded. Only few sources yield quantitative time series for reconstructing abundance values through longer historical periods. Nonetheless, even sporadic quantitative, qualitative or anecdotal sources – and especially their combination – provide valuable insights into changes in fish populations. One advantage of long-term data is that variations in fish populations are often much more pronounced than over short periods. This is demonstrated by the study of Atlantic salmon in the Russian North in the 17th and 18th centuries. Although the data showed a probably high level of inaccuracy due to influences of many uncontrolled factors, there was still a significant positive correlation with temperature during this period because of the large variability of parameters.

The example of the Viennese Danube showed that one source alone rarely provides information about fish communities or populations over a certain period. In particular, when there are no catch records and thus no direct samples from the local rivers, the combination of several sources is needed. In this case, combining fish trading data with fishing laws yielded valuable insights.

Our cases are based on a local or regional level. Sometimes, detecting changes in the distribution of particular species requires a larger scale to determine periods of increasing or decreasing occurrence. A case in point is the bitterling (Van Damme et al. 2007); a limited number of mentions in sources were already helpful to reconstruct a larger picture of changes, for example, the disappearance of this species in Europe in the 17th and 18th centuries because of climatic conditions.

This publication focused on written historical documents, but other sources exist to reconstruct fish population dynamics. The potential of visual sources might be important in specific cases. McClanachan (2009) recently proposed using historical photographs of recreational catches to help reconstruct fish distribution and especially fish length. Archaeozoological remains are valuable in themselves, not only when they complement written sources (see Jackson et al. 2001; Pitcher 2001; Pinnegar & Engelhard 2008; Hanley et al. 2009). Fish bones enable estimates of
fish length and a more reliable determination of species, which is often difficult based on written sources. Furthermore, historical maps can be used to identify habitat conditions in different periods and to conclude changes in the fish community structure (see Weber et al. 2007 for the Swiss Rhône). Often, however, the application of accurate species–habitat relation models is constrained by the low spatial resolution of these maps (see Trexler 1995 for an early example of fish community structure changes). Finally, genetic and DNA studies provide valuable results for reconstructing historical fish communities (Acipenser oxyrinchus: Desse-Berset & Williot 2011; Kirschbaum et al. 2006).

The progress of historical climatology in the past two decades has proved the advantage of combining a large variety of documentary sources and material remains (Pfister 1999). These achievements can serve as a role model for similar studies in other fields such as historical fish ecology. Note, however, that in contrast to anthropogenic climate change, humans have modified riverine ecosystems for centuries, and therefore, investigating the drivers of changes is more complex. Moreover, the possibilities to apply similar modelling methods are limited because standardised field fish surveys have been conducted since only a few decades and cannot be used to calibrate less accurate time series (see Brázdil et al. 2005, 2010). Nevertheless, the explanatory value of modelling the historical presence of fish has been demonstrated in several studies (Lassalle & Rochard 2009; Logez et al. 2012).

Studying the historical dynamics of fish communities and populations requires a detailed investigation of the human-and naturally induced driving forces. For riverine ecosystems, the most important are physical habitat alteration, pollution, fisheries, species introductions (intentional and accidental) and climate change. These forces probably have a different history than in the better-studied marine environments, which suffered mainly from overexploitation (Jackson et al. 2001). In contrast, rivers were subject to a multitude of anthropogenic pressures for centuries if not millennia.

Future research efforts will help to describe the historical trajectories of riverine ecosystems. This is an important step in better assessing the future potential of such ecosystems for restoration or evaluating their behaviour against the background of global change.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Historical sources typology and the reconstruction of long-term historical changes of riverine fish: a case study of the Austrian Danube and northern Russian rivers.