

Fish remains as a source to reconstruct long-term changes of fish communities in the Austrian and Hungarian Danube

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Received: 25 February 2014 / Accepted: 11 May 2015 / Published online: 3 June 2015
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Abstract The main objective of this paper is to investigate how archaeological fish remains and written historical records can contribute to the reconstruction of long-term developments of fish communities along the Austrian and Hungarian Danube. Although such approaches are sensitive to various factors, the chronological subdivision and relative quantification of proxy data demonstrate environmental and faunal changes from Prehistory onwards. Intensification of fisheries, decline of large specimens and massive exploitation of small and young fish point to

increasing pressure along the chronological sequence towards Early Modern times. One result of this impact was the establishment of regulations and laws to protect such fish. At the same time, the rise of aquaculture and common carp cultivation can be viewed as another upshot of human impact on the Danube's environment. Finally, the massive import of salted marine fish reflects a compensation for the undersupply caused by overexploitation of the Danube fish fauna and points to the growing demand for fish as food in late medieval and Early Modern times.

Keywords Archaeoichthyology · Archaeological methods · Fish community change · Austrian Danube · Hungarian Danube

This article is part of the special issue 'Historical ecology of riverine fish in Europe'.

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Introduction

The Danube comprises a multitude of aquatic environments along its course from the German Schwarzwald to Austria, Hungary and further south into the Carpathian Basin. Although the river endangered riparian communities by recurring flooding, humans also exploited the natural habitats along the Danube as documented by numerous archaeological sites along the Austrian and the Hungarian part (river km 2135–1886 and 1796–1581). Excavations here uncovered refuse deposits containing fish remains and prove that fishing has substantially contributed to human nutrition since the Neolithic (Bökönyi 1974; Radu 2003; Bartosiewicz 2013).

The successful identification of many fish bones to species level is certainly based on the availability of reference collections. The investigations of such archaeological remains as proxy data address many societal and ecological questions. Cultural preferences influence various social levels as comparing monastic and aristocratic households or

civil sites including latrines and waste disposal places (Galik 1999). Many factors weaken the signals of such proxies, for example their unknown taphonomic history, their inhomogeneity or the precision of recovery. Fish remains from sieved samples significantly differ from hand-collected samples, which yield only few but large specimens (Jones 1983; Bartosiewicz 1988; Cao et al. 2002; Gobalet 2005; Zohar and Belmaker 2005; Chao et al. 2009). Therefore, screening of sieved sediment samples is a precondition for the reliable recovery of fish remains, independent of diverse taphonomic potentials of preservation in various contexts. Especially latrines offer extraordinary conditions as cavities in which masses of material were concentrated during short time spans and excellent preservation conditions conserved even fragile and tiny fish bones (Heinrich 1995; Brombacher et al. 1998; Nussbaumer and Rehazek 2007).

Ecological approaches usually relate to manmade faunal changes or impacts on ecosystems (Kurlansky 1999; Jackson et al. 2001; Pitcher 2001) and, in the case of fishes, environmental pressure can be illustrated by the size patterns of reconstructed lengths of specific species (Jackson et al. 2001). Nonetheless, information derived from archaeological proxy data cannot be simply transformed into measurable variables. Rather, according to Pauly (1995), they are more like “anecdotes”. According to Jackson et al. (2001) “the precision and clarity of the signal they measure” appears to be somewhat unclear but a framework combining historical and archaeoichthyological data as proxies produces stronger signals on a long-term scale. Nevertheless, the finds along the Austrian and Hungarian part of the Danube clearly bear the potential to detect changes chronologically and at a regional scale in a riverine milieu providing new societal and environmental data beyond written documents (Haidvogel et al. 2014). Using such information about past ecological conditions raises a crucial question related to the provenance of the fish. Especially for the later periods, it often remains uncertain if the archaeological fish remains originated from local waters or if they were traded from distant places. For continental sites such as the upper and middle Danube, this is easy to answer only in the case of marine fish.

The main objective of this paper is to test the capacity of such remains to contribute to reconstructing past fish ecological conditions. This involves (1) analysing the influence of recovery methods on the resulting species list, (2) investigating whether the relative abundance of fish species differs on large spatial and temporal scales, (3) identifying size distributions and (4) comparing the fish remains from the early modern period with written documents to reveal differences between two distinct types of proxy information.

Materials and methods

Provenance of the archaeological fish remains

The archaeoichthyological material comes from sites along the Danube in Austria and Hungary. The Austrian river section is characterized by alpine influences in terms of velocity and temperature. Downstream of Bratislava and Győr the character shifts towards a lowland river, also reflected by a change from a dominance of rheophilic and eurytopic to more limnophilic cyprinids (Schiemer et al. 2004). The Austrian Roman, medieval and post medieval sites are concentrated in the Vienna Basin (Fig. 1: 5–13), which showed—prior to the channelization in the 19th century—the typical pattern of an anastomosing river system. This basin was inhabited by diverse fish communities comprising about 52 native species including the sturgeon species (Schiemer and Waidbacher 1998; Spindler 1997). Austrian fish data include archaeological sites at tributaries, among them a post-medieval cesspit in Salzburg near the Salzach River associated with a tavern (Fig. 1: 1). Ansfelden at the confluence of the Traun and Krems rivers documents a long history of settling activities starting in the Neolithic and terminating after early medieval times (Fig. 1: 2). A late medieval monastic latrine filling in St. Pölten is located close to the Traisen River (Fig. 1: 3). Another post-medieval site, the Carthusian monastery Mauerbach was situated at a brook of the same name; that brook was no doubt too small to sustain fish stocks large enough to supply a larger number of friars (Fig. 1: 4). Foundations of the medieval castle Dunkelstein near the Schwarza River, which discharges into the Leitha River and finally ends in the Danube, also revealed fish remains (Fig. 1: 14). In total, approximately 16,000 fish remains were recovered from the Austrian sites.

The Hungarian sites are situated at the upper part of the Hungarian Danube, approximately halved by the Danube Bend gorge where it takes a sharp turn toward the south. The long course is differentiated in an “upstream” and a “downstream” section. The upstream section of the Hungarian Danube begins at the eastern tip of the Szigetköz region. The sites Börcs-Paphomlok-dűlő (Fig. 1: a), Győr-Szabadrét-domb (Fig. 1: b) and Ménfőcsanak-Széles telep (Fig. 1: c) are situated upstream the hilly Danube Bend gorge near Visegrád. The river flanked by floodplains becomes gradually restricted and offered space for sites in Ács-Vaspusztal (Fig. 1: d), Neszmély-Tekeres (Fig. 1: e), Süttő-Hosszúvölgy (Fig. 1: f), Nyergesújfalu-Téglagyár (Fig. 1: g), Esztergom-Királyi (Fig. 1: h), Pilismarót-I. órtony (Fig. 1: i) and finally several sites at Visegrád (Fig. 1: j) and downstream at Vác (Fig. 1: k).

The downstream section of the Danube starts after the southward turn. Sites of various chronological stages are at



Fig. 1 Map with the Austrian (1–14) and Hungarian sites (a–s) along the Danube and tributaries (line drawing Galik). Data: 1 Pucher (1991); 2 Galik (2008); 3 Galik et al. (2011); 4 Galik (1998), Galik and Kunst (2000), Kunst and Galik (2000); 5–13 data for Vienna: Galik unpubl, Jandl and Mosser (2008), Mosser (2010); data for Carnuntum: Galik unpubl, Galik et al. (2009), Petznek (2012); 14 Galik unpubl, Kühnreiter (2005, 2006). a Bartosiewicz unpubl., b Bartosiewicz et al. (1994), c Bartosiewicz unpubl., d Bartosiewicz

(1989), e Bökönyi (1974), f Bökönyi (1974), g Bökönyi (1974), h Takács unpubl, i Bökönyi (1974), j Bartosiewicz unpubl.; k Bartosiewicz (1995), l Bökönyi (1974), m Takács-Bartosiewicz unpubl., Takács unpubl., n, o Bartosiewicz (2003), Bökönyi (1963), Bökönyi (1958), Takács and Bartosiewicz unpubl., Takács unpubl., Bökönyi (1959), p, q Bökönyi (1974), Bökönyi (1959), r Bökönyi (1974), s Bökönyi (1959)

Békásmegyér (Fig. 1: l) and Óbuda (Fig. 1: m). The river flows to a plain near Budapest and becomes wider and less oxygenated because the floodplain area is significantly broader; numerous sites are located at Buda-Vár (Fig. 1: n, o), in Budapest itself (Fig. 1: p, q) and at Csepel-Háros (Fig. 1: r). To date no archaeological fish bone assemblages are available from Hungary further downstream from the southernmost site Dunapentele (Fig. 1: s). The 52 Hungarian sites reviewed in this study provided approximately 2000 specimens.

Identification and aggregation of data

The archaeoichthyological material was identified using ichthyo-osteological reference collections. Measurements on various skeletal elements were taken according to Morales and Rosenlund (1979), and size reconstructions for cyprinids were calculated according to Radu (2003), Radke et al. (2000), Desse et al. (1989) and Desse and Desse-Berset (2005).

Screening of sieved sediment samples was employed only at the Austrian sites, i.e. the castle Dunkelstein, the mainly prehistoric settlements in Ansfelden as well as the latrine fillings from Petronell, St. Pölten and the Stallburg in Vienna, where most of the fish bones come from. In order to identify the influence of the sampling effort on reconstructed fish species, we correlated the number of identified bones vs. the number of identified species.

The abundance of identified fish species is a descriptor of particular fish assemblages which indicate different

ecological river types. Its reliability does largely depend on high numbers of skeletal remains within the archaeoichthyological samples. However, sample sizes are highly variable in the sites along the Danube, some providing numerous specimens and others only a few finds. Nevertheless, such comparisons can indicate certain ichthyological- (Lepiksaar 2001) and historical developments (Makowiecki 2000). Makowiecki (2003) thoroughly discussed the Polish lowland ichthyofauna based on the archaeological frequencies of species with regards to possible distortion arising from varying numbers of skeletal remains. The specific compositions of species in relation to climatic and chronological periodization including size reconstruction of fishes clearly produced pattern induced by the surrounding habitat of the sites from the Mesolithic towards the medieval period and the Modern Times (Makowiecki 2003). Therefore, the use of such a comparative technique promises to reconstruct ecosystem changes following the diachronic sequences along the Austrian and Hungarian parts of the Danube, although faunal peculiarities might be driven by local and regional developments as well.

Four main units were considered: prehistoric, Roman, medieval, late/post-medieval. The medieval period covers a few finds from the early 9th century, while the major part represents the high medieval era up to the 13th century. The late/post-medieval sequence summarizes the late medieval epoch, with remains from the 14th/15th centuries and Early Modern Times with finds from the 16th/17th centuries. Sites along the Danube in the Vienna Basin were combined as one study site, and sites along different tributaries were

evaluated as a second spatial unit in Austria. In Hungary two main units—the “upstream” section towards Vác and the “downstream section” downstream the bend gorge—were used based on the definition of hydro-morphological units for the Joint Danube Survey (Sommerhäuser et al. 2003). Identified cyprinids were compiled according to their degree of rheophily (Noble et al. 2007).

Finally, the archaeological fish assemblages were compared with two types of written historical sources. For Austria, we used a description of fish species offered for sale at the Viennese fish market in 1540 (Schmelzl 1547; Tab. 1) and for Hungary we took into account the cook-books from Galgóczi in 1622 (Herman 1887; Tab. 1). Such descriptions for an urban market and for human consumption are subject to societal filters that differ from those of archaeological fish remains. Importantly, they are not affected by taphonomic processes.

Results

Sampling effort

Evaluation of hand-collected and sieved sediment samples supported the conclusion that sampling effort, i.e. number of bones collected and identified, influences the species

richness, although outliers exist (Fig. 2). Remains from sieved samples from the two late medieval latrines yielded the highest frequencies and species numbers. The latrine in Vienna yielded 28 and the latrine in St. Pölten 34 species. The Roman latrine did not produce high quantities of specimens or species, whereas the carefully hand-collected Roman sites in the Vienna Basin (Carnuntum) exposed a high diversity of species but a low number of identified specimens. The sieved sediment samples from tributaries at Ansfelden and at the castle Dunkelstein yielded fish remains with a lower species number. Most hand-collected Austrian and Hungarian sites clearly indicated low frequencies of species and specimens. They usually represented large remains of sizeable species, while screening of sieve residues recovered all kinds of fish bones including remains of small species.

Relative abundance of identified species

A few prehistoric sturgeons were recovered in the Hungarian sites. While missing at Austria’s prehistoric site at tributaries, sturgeons were present in Roman sites along the Danube (Figs. 3, 4, 5, 6). The later periods proved Danube sturgeon to be present not only in the Danube but also in sites at the tributaries, although quantitatively they were rare in the late/post-medieval periods. Both sections of the

Fig. 2 Relation of sample size and richness of species from sites including hand collection and screened sieved sediment samples
($y = 1 \times \exp(0.3026 \times x)$)

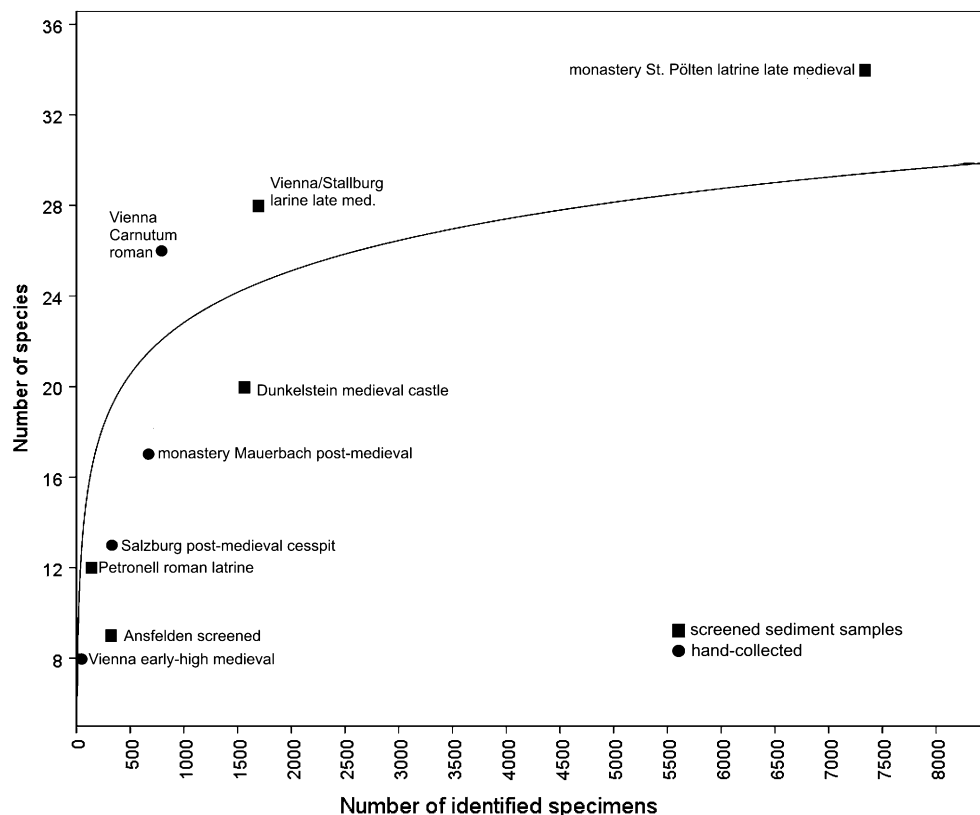


Fig. 3 Relative abundance of fish from the downstream section of the Danube in Hungary (Pisces include all unidentifiable fish bones from an archaeological sample)

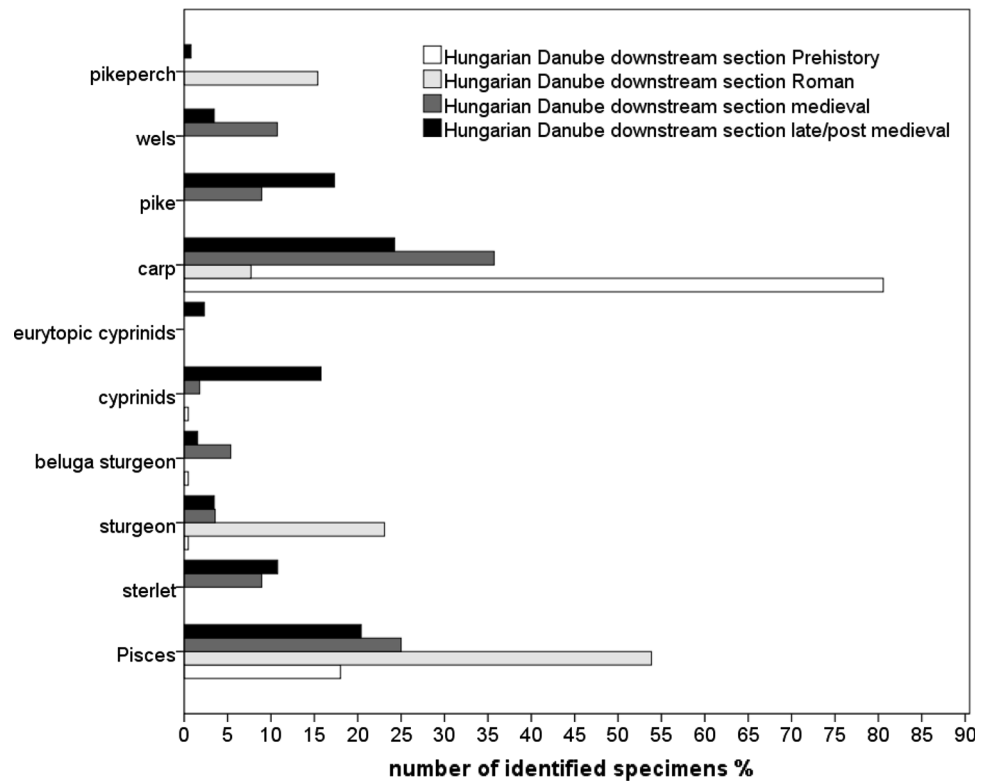


Fig. 4 Relative abundance of fish from the upstream section of the Danube in Hungary

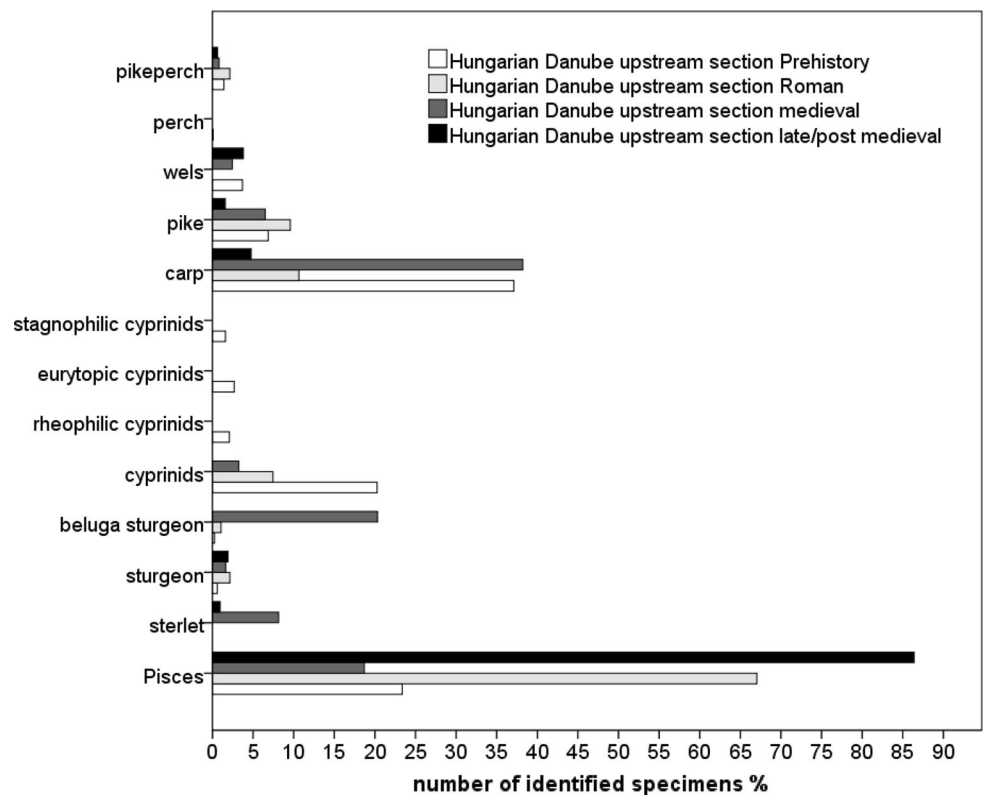


Fig. 5 Relative abundance of fish from the Danube in the Vienna Basin

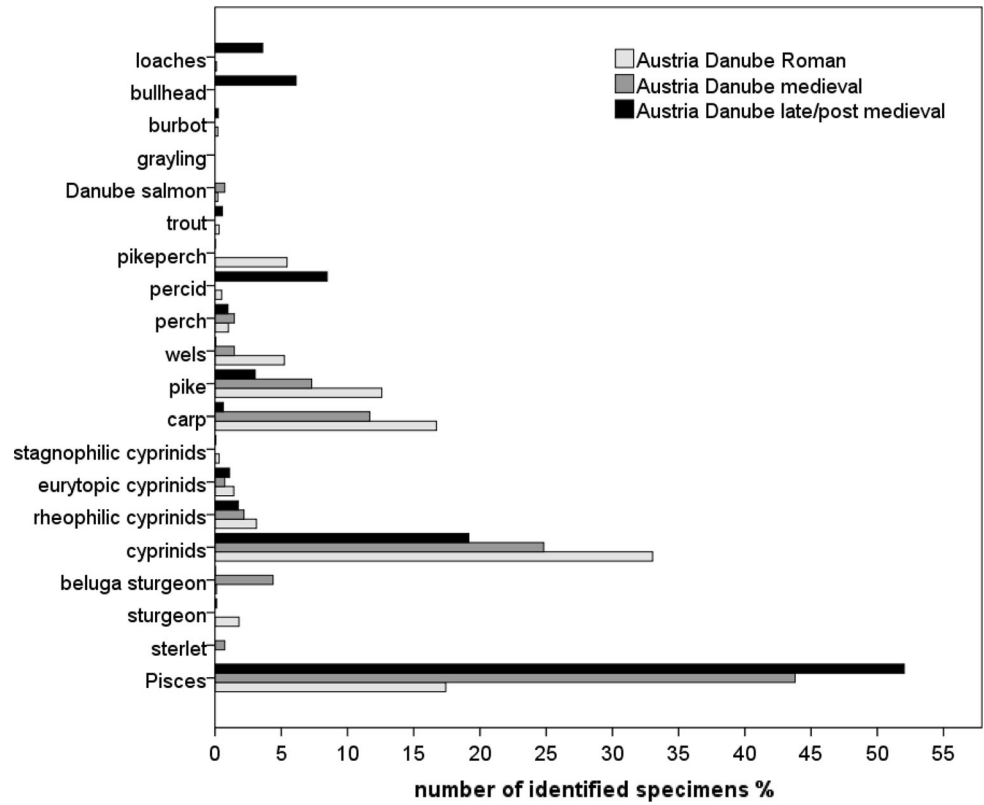
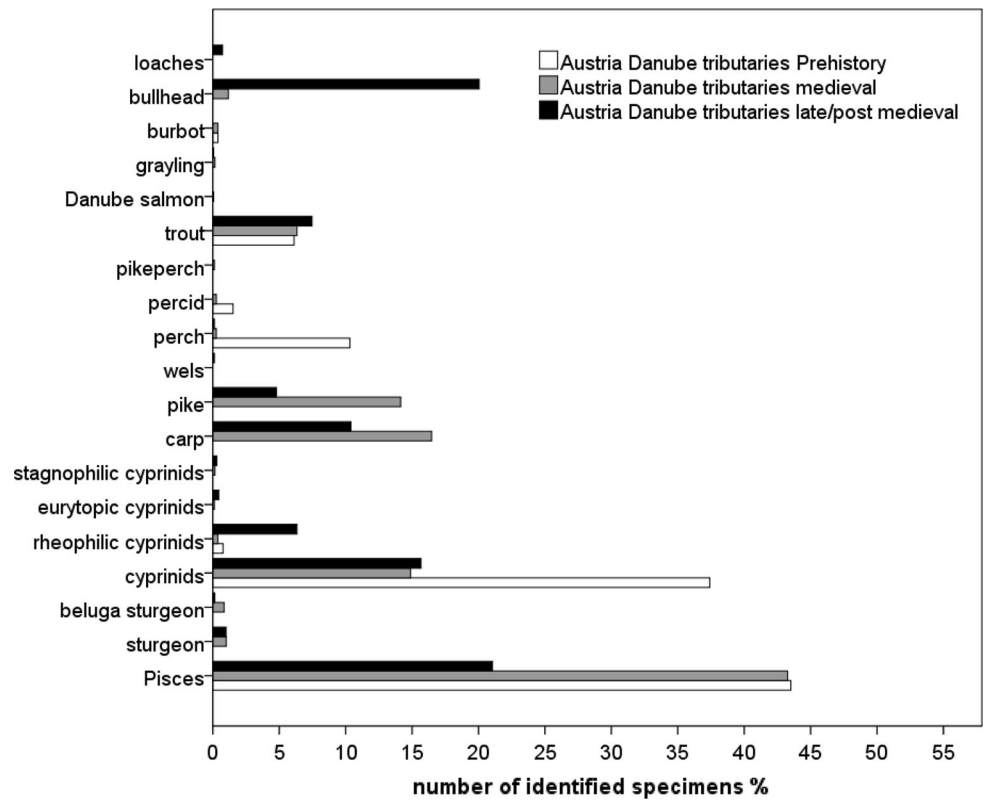


Fig. 6 Relative abundance of fish from the Danube tributaries in Austria



Hungarian Danube reflected a higher abundance especially in the late/post-medieval, with sterlet being the main species in the downstream section (Figs. 3, 4).

All sites revealed highly abundant unidentifiable fish- and unidentifiable cyprinid remains, and only a few rheophilic, eurytopic and limnophilic species were identified in the Hungarian sites (Table 1). Eurytopic cyprinids constitute the highest proportion of cyprinids, except in prehistoric times in the upstream section of the Hungarian Danube (Table 1). All periods in the Vienna Basin and especially at the tributaries contained abundant rheophilic cyprinids, fewer eurytopic and only a few stagnophilic cyprinids.

Common carp (*Cyprinus carpio*) was overwhelmingly represented in the prehistoric contexts at both sections of the Hungarian Danube but it remained absent in Austria's prehistoric site at the Danube tributaries. The Roman-, medieval- and late/post-medieval contexts revealed similar patterns at least for the Vienna Basin and the upstream section of the Hungarian Danube. Although common carp appears quite opposite in the Roman contexts, the decline in abundance from medieval- to late/post-medieval contexts reveal similar pattern at the Hungarian and Austrian sites. The frequencies of pike are similar in Roman contexts as well as the decrease in abundance towards late/post-medieval sites in the Austrian sites and sites at the upstream section of the Hungarian Danube (Figs. 3, 4, 5, 6). The downstream section of the Danube in Hungary yielded no prehistoric or Roman pike remains and showed an increase of pike towards late/post-medieval periods (Fig. 3).

Most of the Austrian and few Hungarian sites yielded perch (*Perca fluviatilis*; Tab. 2). The late medieval latrine in the Vienna Basin contained schraetzer (*Gymnocephalus schraetzer*) and ruffe (*Gymnocephalus cernualbaloni*). Pikeperch (*Sander lucioperca*) was particularly well represented in the Roman contexts at the Austrian and Hungarian Danube but appeared in smaller proportions in later periods and at the Austrian tributaries (Figs. 3, 4, 5, 6).

Wels (*Silurus glanis*) was clearly a regular catch around the Danube, but it remains rare at the Austrian tributaries. Its highest frequency in Austria occurred in the Roman period (Figs. 5, 6). The upstream and downstream sections of the Hungarian Danube indicate a higher abundance in medieval and late/post-medieval times (Figs. 3, 4).

Brown trout (*Salmo trutta f. fario*) occurred in high proportions in all chronological periods at the Danube tributaries in Austria, along with rare evidence of Danube salmon (*Hucho hucho*) and grayling (*Thymallus thymallus*, Table 1). The Danube in the Vienna Basin yielded less brown trout from Roman and late/post-medieval sites but higher frequencies of Danube salmon in Roman and medieval periods. A few finds of burbot (*Lota lota*) imply occasional catches at Austrian sites. Salmonids as well as burbot did not occur in any Hungarian site.

Loaches (*Barbatula* sp., *Cobitis* sp.) were present in the Austrian late medieval- as well as in the Roman latrine. Bullhead (*Cottus gobio*) was documented in the sites related to the Danube and along the tributaries, for example at the medieval castle. Although small fish were present in Roman and medieval times, masses accumulated in the late medieval context only.

Besides above-described species native in the Danube, catadromous eel (*Anguilla anguilla*) occurred in the late medieval latrines in the Vienna Basin and in St. Pölten. Other remains demonstrated the import of marine fish back as far as the reign of the *Imperium Romanum*. The most abundant species was Atlantic chubb mackerel (*Scomber scolias*). While the medieval castle yielded only a single specimen, the latrines produced large numbers of herring vertebrae. Other imported species included cod as stock fish (*Gadus morhua*) and flatfish, mainly plaice (*Pleuronectes platessa*) but also sole (*Solea solea*) and turbot (*Scophthalmus maximus*) in monastic contexts and in the cesspit filling of the tavern in Salzburg (Fig. 7; Table 1). Contrary to the Austrian evidence, so far no Hungarian sites have yielded marine fish remains.

Changes in size distribution of cyprinids and common carp

Most of the material indicated cyprinids in the size range of 30–40 cm and sometimes even larger (Fig. 8). The Roman latrine yielded only few data, revealing small fish measuring only about 10 cm (Fig. 8 below). The late medieval latrines generated a completely different pattern in terms of the “mass” occurrence of remains but also in size, most of the fish smaller than 10 cm (Fig. 8 above). The size distribution of common carp suggests a size transformation over time as well. Common carp from the Roman contexts widely ranged from about 20 cm up to very large specimens exceeding 1 m in length (Fig. 9). Medieval individuals indicated a shift towards individual lengths of 30–50 cm. Finally, the late/post-medieval finds implied size reduction and standardization at balanced median values of 40 cm (Fig. 9).

Comparison of archaeological remains and written historical documents

The written sources confirm the fish species detected in the archaeological records but also complement and complete the ichthyofaunal evidence. Besides sterlet and beluga sturgeon, Schmelzl (1547) additionally described the availability of waxdick and stellate sturgeon at the fish market in Vienna. Cyprinids such as silver bream, blue bream, dace, vimba bream or schneider were not explicitly mentioned in Galgóczi's cookbook (1622) and were most

Table 1 Number of identified fish remains from the Austrian and Hungarian sites

	Austria tributary prehistory	Austria tributary medieval	Austria tributary late/post medieval	Austria Danube Roman	Austria Danube medieval	Austria Danube late/post medieval	Hungary upstream section prehistory
Pisces	185	1868	683	308	121	4493	279
<i>Acipenserinae</i>		19	27	18		9	7
<i>Acipenser ruthenus</i>					1		
<i>Huso huso</i>		16	4	1	6	1	3
<i>Anguilla anguilla</i>			22			31	
Cyprinidae	98	295	440	336	34	1527	242
<i>Ballerus ballerus</i>			1				
<i>Abramis brama</i>		1	2	3	1	1	16
<i>Alburnoides bipunctatus</i>						1	
<i>Alburnus alburnus</i>				1		7	
<i>Aspius aspius</i>				17			
<i>Barbus barbus</i>		2	17	8	3	16	8
<i>Blicca bjoerkna</i>			1	2		4	1
<i>Carassius carassius</i>		1		1		1	5
<i>Chondrostoma nasus</i>			2	1		7	
<i>Cyprinus carpio</i>		317	309	168	16	65	443
Gobio sp.			8			19	
<i>Leuciscus</i> sp.	1	2	72	2		72	
<i>Leuciscus cephalus</i>	1	3	45				
<i>Leuciscus idus</i>			1	2			15
<i>Leuciscus leuciscus</i>			2				
<i>Leuciscus souffia</i>						1	
<i>Pelecus cultratus</i>							1
<i>Phoxinus phoxinus</i>			25			12	
<i>Rutilus rutilus</i> /sp.		1	9	9		79	15
<i>Scardinius erythrophthalmus</i>		2	5	1		3	
<i>Tinca tinca</i>			3	1			14
<i>Vimba vimba</i>							1
Cobitidae/Balitoridae			20	1		277	
<i>Silurus glanis</i>			3	35	2	3	44
<i>Esox lucius</i>		328	158	128	10	324	82
<i>Thymallus thymallus</i>		3	1				
<i>Hucho hucho</i>		1					
<i>Salmo trutta f. fario</i>	17	120	204	2	1	43	

Table 1 continued

	Austria tributary prehistory	Austria tributary medieval	Austria tributary late/post medieval	Austria Danube Roman	Austria Danube medieval	Austria Danube late/post medieval	Hungary upstream section prehistory	Hungary upstream section late/post medieval	Hungary downstream section prehistory	Hungary downstream section medieval	Hungary downstream section late/post medieval
<i>Lota lota</i>	1	7		2		19					
<i>Cottus gobio</i>		22	548			471					
Percidae	4	5		8		480					
<i>Sander lucioperca</i>		2		54		1					17
<i>Perca fluviatilis</i>	27	5	3	10	2	75					1
<i>Gymnocephalus cernua/baloni</i>						103					
<i>Gymnocephalus schraetser</i>						72					
Gadus sp.			85			1					
Scomberidae				17							
<i>Clupea harengus</i> /sp.		1	132	1		131					
Pleuronectiformes			6								
<i>Pleuronectes platessa</i>			60					1			
<i>Psetta maxima</i>			5								
Soleidae			2								
Marine fish							2				
	Hungary upstream section Roman	Hungary upstream section medieval	Hungary upstream section late/post medieval	Hungary downstream section prehistory	Hungary downstream section Roman	Hungary downstream section medieval	Hungary downstream section prehistory	Hungary downstream section medieval	Hungary downstream section late/post medieval		
Pisces	63	23	273	38	7	14				53	
Acipenserinae	2	2	6	1	3	2				9	
<i>Acipenser ruthenus</i>		10	3			5				28	
<i>Huso huso</i>	1	25		1		3				4	
<i>Anguilla anguilla</i>											
Cyprinidae	7	4		1		1				41	
<i>Ballerus ballerus</i>											
<i>Abramis brama</i>											6
<i>Alburnoides bipunctatus</i>											
<i>Alburnus alburnus</i>											
<i>Aspius aspius</i>											
<i>Barbus barbus</i>											
<i>Blicca bjoerkna</i>											
<i>Carassius carassius</i>											

Table 1 continued

	Hungary upstream section Roman	Hungary upstream section medieval	Hungary upstream section late/post medieval	Hungary downstream section prehistory	Hungary downstream section Roman	Hungary downstream section medieval	Hungary downstream section late/post medieval
<i>Chondrostoma nasus</i>							
<i>Cyprinus carpio</i>	10	47	15	170	1	20	63
Gobio sp.							
<i>Leuciscus</i> sp.							
<i>Leuciscus cephalus</i>							
<i>Leuciscus idus</i>							
<i>Leuciscus leuciscus</i>							
<i>Leuciscus souffia</i>							
<i>Pelecus cultratus</i>							
<i>Phoxinus phoxinus</i>							
<i>Rutilus rutilus</i> /sp.							
<i>Scardinius erythrophthalmus</i>							
<i>Tinca tinca</i>							
<i>Vimba vimba</i>							
Cobitidae/Balitoridae							
<i>Silurus glanis</i>		3	12			6	9
<i>Esox lucius</i>	9	8	5			5	45
<i>Thymallus thymallus</i>							
<i>Hucho hucho</i>							
<i>Salmo trutta f. fario</i>							
<i>Lota lota</i>							
<i>Cottus gobio</i>							
Percidae							
<i>Sander lucioperca</i>	2	1	2		2		2
<i>Perca fluviatilis</i>							
<i>Gymnocephalus cernua/baloni</i>							
<i>Gymnocephalus schraetser</i>							
Gadus sp.							
Scomberidae							
<i>Clupea harengus</i> /sp.							
Pleuronectiformes							
<i>Pleuronectes platessa</i>							
<i>Psetta maxima</i>							
Soleidae							
Marine fish							

probably summarized as “Weißfisch” in Schmelzl’s list (Table 2). Other cyprinids were commented in the cookbook, including barbel, common carp, common bream, bleak, asp, nase, ide, rudd or tench. Among percids, only zingel occurred neither in the Austrian nor in the Hungarian archaeological records. Schraetzer and ruffe appeared in the list of the Viennese fish market as well as in the archaeological record. Recipes for small fish such as loaches, bullhead but also burbot indicate exploitation in post-medieval Hungary. Other species absent from the Hungarian archaeological records, such as grayling, trout and Danube salmon, were again documented in the form of recipes only. Whitefish and alpine charr are mentioned in Schmelzl’s (1547) list for the Viennese fish market but lack accompanying archaeological proof as yet.

Discussion

Archaeological fish remains produce distorted pictures that are biased by taphonomic history, beginning with fishing, trade and consumption and ending with preservation. Beyond methodological factors such as the expertise or the method of recovery, which massively influence the richness of species by “sampling” efforts, the state of preservation and inconsistent quantities of identifiable bones impedes chronological and contextual comparisons. The proxies provide a reliable signal at least for the regularly hand-collected large fish species, bearing in mind that limited material may reflect regional—rather than diachronic variations.

However, as a recurring nutritive resource, large migratory sturgeons were targeted from prehistoric times on at the Hungarian part of the Danube. The first Austrian sturgeon remains date to the Roman period, while the prehistoric site Ansfelden is located outside their natural migration routes and no evidence of prehistoric sturgeon exploitation has been proven to date along Austria’s Danube. Besides the archaeologically evidenced sterlet and beluga sturgeon, a higher variety of sturgeon species is expectable (Schmelzl 1547; Zauner 1997). The Austrian Danube offered good sturgeon fishing grounds (Balon 1968) and, since medieval times, sturgeon fishing intensified (Bartosiewicz and Bonsall 2008). As opposed to Hungary, the assumption is that sturgeon populations in Austria already declined in Early Modern times, which may explain their disappearance from fishing regulations in the 16th century (Haidvoogl et al. 2013). Especially the economically and symbolically important beluga sturgeons were continuously delivered from Hungary to the Viennese fish market (Reischl 1921/1922) and even transported to sites at small Danube tributaries (Galik and Kunst 2000). As indicated by archaeoichthyological remains

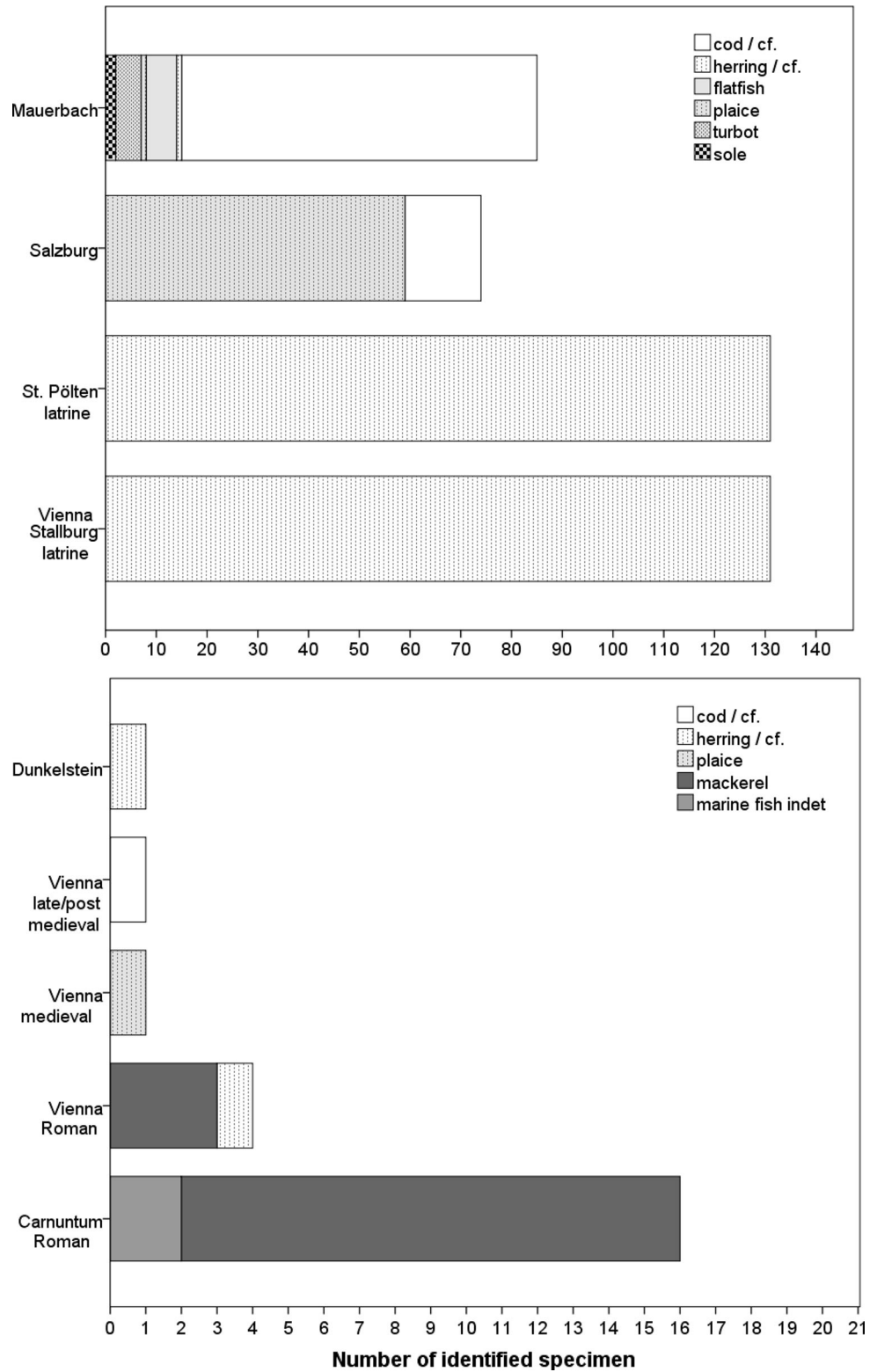
excessive fishing finally reduced the size and abundance of long-distance migratory sturgeons along the Hungarian part as well (Balon 1968; Bartosiewicz et al. 2008; Guti 2008).

The remains from the Roman latrine in the Vienna Basin indicate another pattern as the late/post-medieval latrine fillings. The Roman site reveals the use of only a few small sized fishes although the sediment was carefully sieved. Even smaller sizes and intensified exploitation of juvenile cyprinids and other small species indicate changes in fisheries in the late/post-medieval times in Austria. Historical records refer to these environmental impacts, in particular fishing laws such as introduced by Albrecht V in 1412 for the Austrian part of the Danube (Uhlirz 1900). They prohibited the use of specific nets to protect purposefully juvenile individuals of larger species as well as other small fishes. Although not present in Hungarian sites, small species such as bullhead, loaches as well as lamprey represented popular delicacies as indicated by Galgóczi’s (1622) cookbook. Comparable other sites with latrines in Switzerland and Germany probably raise this phenomenon on specific exploitation of small and young fish to Central European behaviour at this specific period (Heinrich 1995; Brombacher et al. 1998; Hüster-Plogmann 2006; Nussbaumer and Rehazek 2007).

Common carp and other cyprinids and pike are abundant and important fish in Austria and Hungary and probably mirror an increase of fishing intensity towards the medieval—but a decrease of specimens towards the late/post-medieval periods. The Austrian common carp remains reflect human impact at the ecosystem, too. Comparable to Hungarian Neolithic exploitation (Bartosiewicz 2013) the Austrian Roman contexts demonstrate exploitation of the Danube’s wild carp populations, revealing a wide range of individual size. Common carp was stocked in ponds since the early medieval period (Hoffmann 1994, 1995, 1996, 2005; Balon 1995) and massively reared in the High Middle Ages. The estimated number of man-made Hungarian fishponds ranges from 3000 to 4000 from the 11th to the 13th century (Pesty 1867). Loads of harvested reared common carps of similar size and weight suggest a compensation of declining natural wild carp stocks; this is underlined by the “size standardization” at about 40 cm individual lengths in medieval and late/post-medieval contexts. Schmelzl (1547) differentiates between certain forms of common carp “*Karpfen*, *Seekarpfen*” and “*Theißkarpfen*” most probably from the Tisza River. Besides these forms, Bohemian reared common carp was transported to the Viennese fish market as well (Wacha 1956).

The documentation of assumed ecological differences and changing fish communities between the Austrian and the Hungarian part of the Danube is hampered by the aforementioned methodological insufficiencies and is restricted to mainly larger eurytopic species. Even such hand-

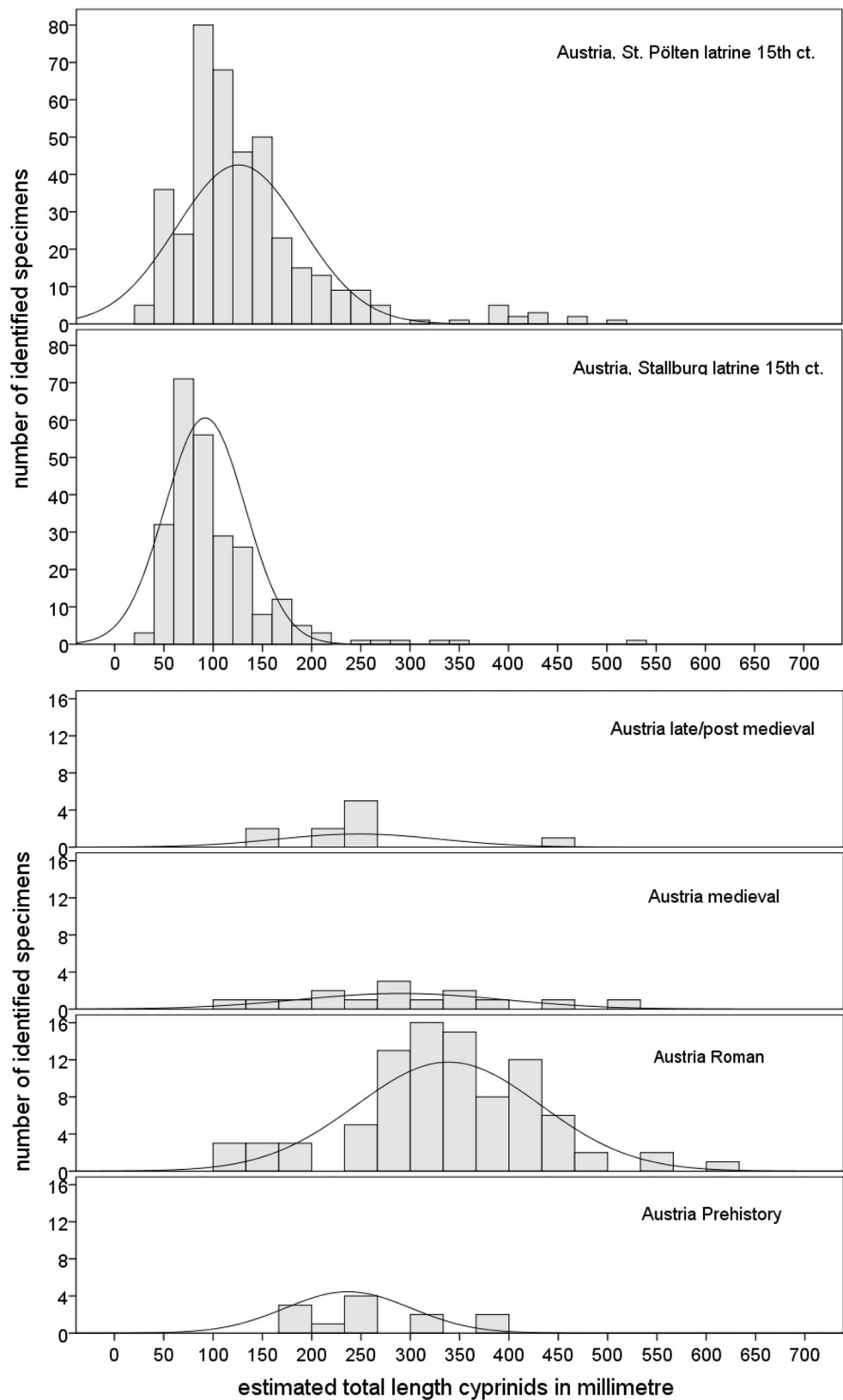
Fig. 7 Abundance of marine fish remains in Austria (*diagram above lists* Austrian sites with numerous remains of marine fish, *diagram below lists* sites with rare finds of marine fish)



collected and large fish remains indicate that species such as sturgeon, common carp or pike had been transported to remote sites at Austria’s Danube tributaries, outside their natural habitat. At a finer level, the sieved samples reveal a

correspondence of species composition and Danube habitats in the Vienna Basin and the tributary sites. The conspicuous absence of trout in early medieval Ansfelden might be explained as a pattern of Slavic people’s

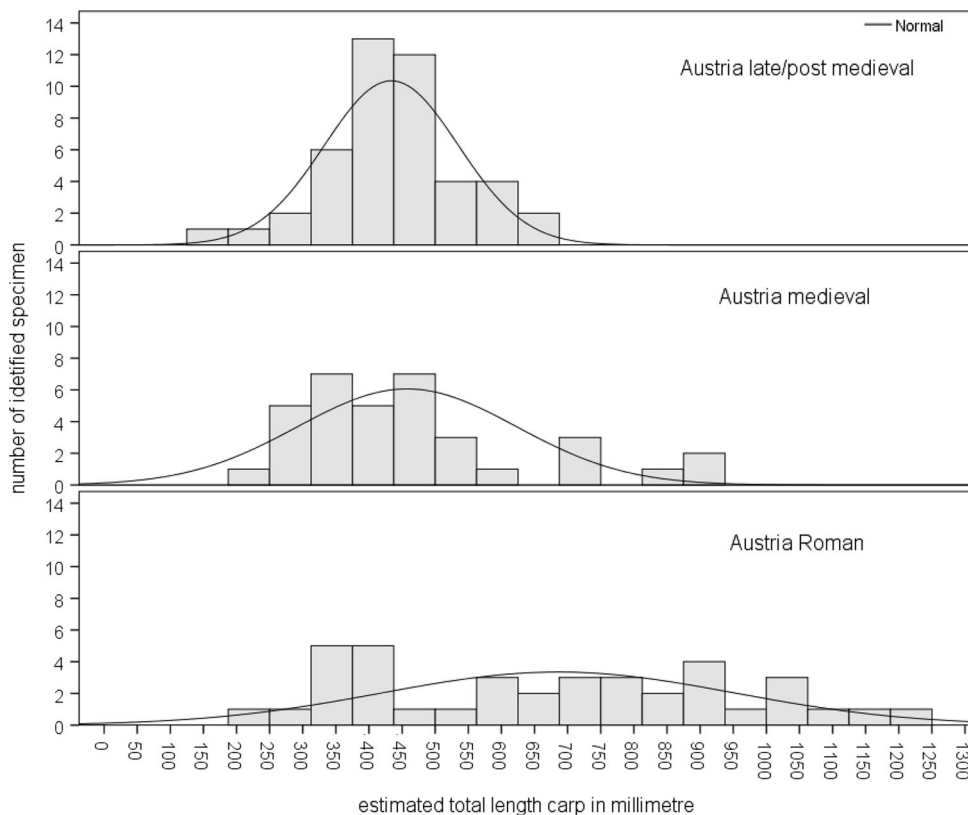
Fig. 8 Estimated size distribution of cyprinids from Austrian sites (*diagram above* indicates the size distribution of cyprinids from late medieval latrine fillings in Vienna—Stallburg and St. Pölten, *diagram below* indicates the size distribution of cyprinids from prehistoric to late/postmedieval sites and only the Roman assemblage contains remains from a latrine filling)



preference for cyprinids, whereby potential taphonomic conditions or environmental changes may also have played a role. Typical species in the samples such as schraetzer

and ruffe indicate exploitation of local Danube fish in the Vienna Basin (Zauner 1996). A good representation of large remains of pikeperch is expected because they are

Fig. 9 Estimated size distribution of common carp at sites in Austria



more easily recognisable even by hand collection. They accumulated in Roman time but prove to be sporadic in later periods. Such a pattern indicated by these archaeoichthyological remains may relate to environmental changes as pikeperch requires aerated waters. Even subtle shifts in temperature or velocity (Bartosiewicz and Bonsall 2004) impact the post-Roman Danube habitats in Austria and Hungary, although without historical habitat information this assumption is difficult to prove. Nevertheless Galgóczi's (1622) cookbook mentions only a single pikeperch recipe, at least pointing to a lesser culinary interest in the 17th century. The absence of grayling and salmonids in the Hungarian part of the Danube might be argued by temperature thresholds and fewer suitable habitats and these species occurred mainly at sites along the Danube tributaries even in Austria. Nevertheless, the Hungarian cookbook comprises numerous "salmonid"-recipes, indicating a 17th century supply of these species from cold-water tributaries or, more likely, fish trade. Austrian historical sources reveal brown trout and alpine charr as fresh deliveries to the Viennese fish market in the 16th century (Wacha 1956). Based on our samples the absence of burbot in Hungary is contradicted by ten recipes in the cookbook, underlining the popularity of this fish in Hungarian gastronomy.

Imported and preserved marine fish certainly reflect a demand for Mediterranean cuisine and life style in land-

locked Central Europe in Roman times (Hüster-Plogmann 2002; Galik 2004; Van Neer and Ervynck 2004; Hüster-Plogmann 2006; Galik et al. 2009). Most of the imported fish was certainly of Mediterranean origin, but a Roman pit filling in Vienna at the "Freyung" yielded, beyond few Atlantic chub mackerel remains, vertebrae resembling small-sized herring and strongly indicating the import of Atlantic fishes. The late medieval eel remains may represent preserved and transported fish as well, but historical records show that eel migrated towards two Austrian regions. The first was the Lainsitz in Lower Austria, where eel entered from the Elbe-system. The second was Lake Constance via the Rhine River (Spindler 1997). Nonetheless, the massive medieval and post-medieval import of marine fish (Lampen 2000; Locker 2001)—even to deep inland areas (Zeiringer 1991) associated with increasing fish farming—suggests a compensation for an under-supply of resources with cheap salted fish as mentioned in the "Fisch Preis Taxe in Eger" in 1465 (Abel 1980). Although there is no archaeological evidence for such fish remains in Hungary, several recipes were prepared using marine fish in the incomplete manuscript of Fay's Hungarian cookbook from the 17th century (Herman 1887).

Concluding, our investigations demonstrated the potential of using fish remains and written historical records for reconstructing long-term changes of the Danubés fish communities but also certain limitations as well as the

Table 2 List of fish species mentioned in manuscript of Galgóczi's cookbook in 1622 and fish listed by Schmelzl (1547) available at the Viennese fish market in comparison to the late/post-medieval archaeoichthyological distribution in Hungary and Austria

		Galgóczi's cookbook 1622 number of recipes	Late/post medieval Hungary	Schmelzl (1547)	Late/post medieval Austria
Lamprey	<i>Eudontomyzon</i> sp.	3		Neunaugen	
Sturgeon	<i>Acipenser</i> sp.	12	X		X
Sterlet	<i>Acipenser ruthenus</i>	11	X	Stierl	X
Waxdick	<i>Acipenser güldenstedti</i>			Tück	
Stellate sturgeon	<i>Acipenser stellatus</i>			Schierken	
Beluga sturgeon	<i>Huso huso</i>	12	X	Hausen	X
Eel	<i>Anguilla anguilla</i>	2		Aal	X
Gudgeon	<i>Gobio</i> sp.	1		Greßling	X
Barbel	<i>Barbus</i> sp.	3	X	Barben	X
Silver bream	<i>Blicca bjoerkna</i>		X		X
Common carp	<i>Cyprinus carpio</i>	19	X	Karpfen	X
Common carp	<i>Cyprinus carpio</i>			Seekarpfen, Theißkarpfen	
Crucian carp	<i>Carassius carassius</i>	8	X	Garauß	X
Bream	<i>Abramis brama</i>	1	X	Brachsen	X
Blue bream	<i>Ballerus ballerus</i>				X
Bleak	<i>Alburnus alburnus</i>	1			X
Asp	<i>Aspius aspius</i>	1			X
Nase	<i>Chondrostoma nasus</i>	1		Näsling, Kräuterling	X
Ide	<i>Leuciscus idus</i>	1	X	Nerfling	X
Chub	<i>Leuciscus cephalus</i>			Aelten	X
Dace	<i>Leuciscus leuciscus</i>				X
Roach	<i>Rutilus rutilus</i>		X	Rothäugl	X
Rudd	<i>Scardinius erythrophthalmus</i>	1			X
Tench	<i>Tinca tinca</i>	6	X		X
Ziege	<i>Pelecus cultratus</i>		X	Sichling	
Minnow	<i>Phoxinus phoxinus</i>			Elritze, Pfrillen	X
Vimba bream	<i>Vimba vimba</i>		X		
Schneider	<i>Alburnoides bipunctatus</i>				X
Spined loach	<i>Cobitis</i> sp.			Steinbeiß	X
Weather loach	<i>Misgurnus fossilis</i>	13		Bißgurre	
Stone loach	<i>Barbatula barbatula</i>	4		Grundel	X
Sheatfish	<i>Silurus glanis</i>	9	X	Scheiden	X
Pike	<i>Esox lucius</i>	22	X	Hecht	X
Whitefish	<i>Coregonus</i> sp.			Reinanken	
Alpine charr	<i>Salvelinus alpinus</i>			Seibling	
Trout	<i>Salmo trutta f. fario</i>	8		Forellen	X
Danube salmon	<i>Hucho hucho</i>	6		Huchen	X
Atlantik salmon	<i>Salmo salar</i>	1			
Grayling	<i>Thymallus thymallus</i>	3		Aesche, Mailing, Sprenzling	X
Burbot	<i>Lota lota</i>	10		Rotten?	X
Bullhead	<i>Cottus gobio</i>	3		Koppen	X
Perch	<i>Perca fluviatilis</i>	2	X	Barsche	X
Pikeperch	<i>Sander lucioperca</i>	1	X	Schille	X
Zingel	<i>Zingel zingel</i>	1		Zindel?	
Schraetser	<i>Gymnocephalus schraetser</i>	1			X
Ruffe	<i>Gymnocephalus cernua</i>			Wachsfisch	X

dependence from the methodological approaches e.g. of sampling. Although only proxy data are involved, the species found and the frequency of bones clearly indicate the relation between the fish community and human interaction and impact on the Danube's environment. Our results strongly encourage improvement and standardization of archaeological recovery methods and routine screening for fish remains. Such data can provide historical investigations at finer chronological and geographical resolutions along the various riverine habitats of the Danube. They have the potential to enlighten even local changes in ecology and fish population. The incorporation of new and well established bio-molecular methods with still rising potential and reliability such as analyses of stable isotopes (Barrett et al. 2004, 2011; Orton et al. 2011; Fuller et al. 2012) and aDNA (Hlinka et al. 2002; Arndt et al. 2003) can improve the identification of fish species and elicit the provenance of traded fish. Most promising for the future will be the combination of methods such as morphology, osteometry, isotopes and aDNA (Ólafsdóttir et al. 2014) even for the development of fresh water fish populations along the Danube.

Acknowledgments We sincerely thank all colleagues who provided us with the abundant fish bones and further information that formed the basis of this study. This research was funded by the Austrian Science Fund (FWF Project Number I 450-B16).

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References

- Abel W (1980) Strukturen und Krisen der spätmittelalterlichen Wirtschaft. Quellen und Forschung zur Agrargeschichte, 32
- Arndt A, Van Neer W, Helleman B, Robben J, Volckaert F, Waelkens M (2003) Roman trade relationships at Sagalassos (Turkey) elucidated by ancient DNA of fish remains. *JAS* 30:1095–1105
- Balon EK (1968) Einfluß der Fischerei auf die Fischgemeinschaften der Donau. *Arch. für Hydrobio, Suppl.* XXXIV 3:228–249
- Balon EK (1995) Origin and domestication of the wild carp, *Cyprinus carpio*: from Roman gourmets to the swimming flowers. *Aquaculture* 129:3–48
- Barrett JH, Locker A, Roberts CM (2004) The origins of intensive marine fishing in medieval Europe: the English evidence. *Proc R Soc Lond B* 271:2417–2421
- Barrett JH, Orton DC, Johnstone C, Harland J, van Neer W, Eryvnc A, Roberts CM, Locker A, Amundsen C, Bødker Enghoff I, Hamilton-Dyer S, Heinrich D, Hufthammer AK, Jones AKG, Jonsson L, Makowiecki D, Pope P, O'Connell TC, de Roo T, Richards MP (2011) Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. *JAS* 38(7):1516–1524
- Bartosiewicz L (1988) Water sieving experiment at Örménykut site 54. In: Jró M, Költö M (eds) *Archaeometrical research in Hungary*. National Centre of Museums, Budapest, pp 267–274
- Bartosiewicz L (1989) Animal remains from the fort. In: Gabler D (ed) *The Roman fort of Ács-Vaspuszta (Hungary) on the Danubian Limes. Part ii*. BAR Br. Ser., vol 531, pp 600–623
- Bartosiewicz L (1995) Animals in the urban landscape in the wake of the Middle Ages. BAR International Series, 609. Tempus Reparatum, Oxford
- Bartosiewicz L (2003) Eat not this fish—a matter of scaling. In: Guzmán AF, Polaco OJ, Aguilar FJ (eds) *Presencia de la arqueociología en México*. Conaculta-INAH, México DF, pp 19–26
- Bartosiewicz L (2013) Early Neolithic Fishing in the Middle Tisza Region, Hungary. *Archaeofauna* 22:133–144
- Bartosiewicz L, Bonsall C (2004) Prehistoric fishing along the Danube. *Antaeus* 27:253–272
- Bartosiewicz L, Bonsall C (2008) Complementary taphonomies: Medieval sturgeons from Hungary. In *Archéologie du Poisson. 30 ans d'archéologie-ichtyologie au CNRS. Hommage aux travaux de Jean Desse et Nathalie Desse-Berset*. In: Béarez P, Grouard S, Clavel B (eds) *XXVIIIe rencontres internationales d'archéologie et d'histoire d'Antibes*, Éditions APDCA, Antibes, pp 35–45
- Bartosiewicz L, Bonsall C, Şişu V (2008) Sturgeon fishing along the Middle and Lower Danube. In: Bonsall C, Boroneanţ V, Radovanović I (eds) *The Iron Gates in prehistory. New perspectives*. BAR International Series, vol 1893, pp 39–54
- Bartosiewicz L, Takács I, Székelyhidy I (1994) Problems of size determination in common carp (*Cyprinus carpio*). In: Van Neer W, *Fish exploitation in the past, Proceedings of the 7th meeting of the ICAZ Fish Remains Working Group*, 6–10 September 1993, Leuven, vol 274. *Annales du Mus. Royal de l' Afrique Central, Sciences Zoologiques*, pp 55–60
- Bökönyi S (1958) Die Tierknochenfunde der Ausgrabungen im Burgpalast von Buda. *Bp. Rég.* 18:455–486
- Bökönyi S (1959) Die frühalluviale Wirbeltierfauna Ungarns (Vom Neolithikum bis zur La Tène-Zeit). *Acta Archaeol Hung* 11:39–102
- Bökönyi S (1963) A budai várpalota ásatásának állatsontanyaga. II.—Die Tierknochenfunde der Ausgrabungen im Burgpalast von Buda. II. *Bp. Rég.* 20:395–425
- Bökönyi S (1974) History of domestic animals in Central and Eastern Europe. *Akadémiai Kiadó*, Budapest
- Brombacher C, Helmig G, Hüster-Plogmann H, Rentzel P, Rodel S, Veszeli M (1998) und was davon übrig bleibt—Untersuchungen an einem Latrinenschacht an der Bäumleingasse 14 (1992/20). *Jahresber Archäol Bodenforsch des Kantons Basel-Stadt* 1998:93–131
- Cao Y, Larsen DP, Hughes RM, Angermeier PL, Patton TM (2002) Sampling effort affects multivariate comparisons of stream assemblages. *J N Am Benthol Soc* 21(4):701–714
- Chao A, Colwell RK, Lin CW, Gotelli NJ (2009) Sufficient sampling for asymptotic minimum species richness estimators. *Ecology* 90:1125–1133
- Desse J, Desse-Berset N, Rocheteau M (1989) Les profils rachidiens globaux. Reconstitution de la taille des poissons et appréciation du nombre minimal d'individus à partir des pièces rachidiennes. *Rev de Paleobiol* 8/1:89–94
- Desse J, Desse-Berset N (2005) Que mesure “Jojo”, que peçse “Louis”? *Rev Paléobiol* 10:155–158
- Fuller BT, Müldner G, Wim Van Neer, Eryvnc A, Richards MP (2012) Carbon and nitrogen stable isotope ratio analysis of freshwater, brackish and marine fish from Belgian archaeological sites (1st and 2nd millennium AD). *J Anal At Spectrom* 27:807–820

- Galik A (1998) Fischreste aus der Kartause Mauerbach. In: Kunst GK (ed) *Reste von Fastentieren und andere bemerkenswerte Tierreste aus der Kartause Mauerbach*, vol 37. *Fundberichte aus Österreich*, pp 397–402
- Galik A (1999) Fischreste aus mittelalterlichen bis neuzeitlichen Fundstellen: Bedeutung und Aussagekraft dieser kleinen archäozoologischen Funde. *Beiträge zur Mittelalterarchäologie in Österreich* 15:197–206
- Galik A (2004). Archäozoologische und Kulturhistorische Aspekte der Tierknochenvergesellschaftungen aus dem Amphitheater von Virunum. In: Jernej R, Gugl CH (eds) *Virunum, das römische Amphitheater. Die Grabungen 1998–2001*, Wieser Verlag, Klagenfurt/Celovec, pp 395–452
- Galik A (2008) Die Fischreste. In: Trebsche P (ed) *Die Höhensiedlung “Burgwiese” in Ansfelden (Oberösterreich)*. *Linzer Archäol. Forsch* 38/2:307–315
- Galik A, Kunst GK (2000) Weitere Tierknochenuntersuchungen in der Kartause Mauerbach. In: Kreitner T (ed) *Vorbericht über die archäologischen Untersuchungen in der Kartause Mauerbach 1999*. *Fundber aus Österreich* 38(1999):409–412
- Galik A, Kunst GK, Radbauer S (2009) Fish remains from a stratigraphic sequence from the Roman civil town of Carnuntum (Lower Austria). In: Makowiecki D, Hamilton-Dyer S, Riddler I, Trzaska-Nartowski N, Makohonienko M (eds) *Fishes—culture—environment. Through archaeoichthyology, ethnography and History. The 15th meeting of the ICAZ Fish Remains Working Group (FRWG) September 3–9, 2009 in Poznań and Toruń, Poland*. *Environ Culture* 7:103–107
- Galik A, Schneider MT, Forstenpointner G (2011) Die tierischen Überreste aus einer spätmittelalterlichen Latrine im Augustiner Chorherrenstift in St. Pölten. In: Risy R (ed) *St. Pölten: kompakt*. (Band 1) Begleitpublikation zur gleichnamigen Ausstellung im Stadtmuseum St. Pölten 2011/12, pp 91–103
- Gobalet KW (2005) Comment on “size matters: 3-mm sieves do not increase richness in a fishbone assemblage from Arrawarra I, an Aboriginal Australian shell midden on the mid-north coast of New South Wales, Australia” by Vale and Gargett. *J Am Sci* 32:643–645
- Guti G (2008) Past and present status of sturgeons in Hungary and problems involving their conservation. *Fundam Appl Limnol/Arch für Hydrobiol Suppl.* 162, 18, 1/2:61–79
- Haidvogel G, Galik A, Pont D (2013) Vers une histoire de la biodiversité piscicole du Danube autrichien: apports croisés des sources archéologiques et écrites. *Rev du Nord Hors Série Collection Art et Archéologie* 19:131–142
- Haidvogel G, Lajus D, Pont D, Schmid M, Jungwirth M, Lajus J (2014) 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. *Ecol Freshw Fish* 23(4):498–515. doi:10.1111/eff.12103
- Heinrich D (1995) Untersuchungen an Fischresten aus Kloaken des 17. Jahrhunderts in Höxter sowie Bemerkungen den dort geborgenen Knochen von Froschlurchen. *Ausgrabungen und Funde in Westfalen—Lippe (Münster)* 9B:381–398
- Herman O (1887) *A Magyar Halászat Könyve [The book of Hungarian fisheries]*. A Királyi Magyar Természettudományi Társulat, Budapest
- Hlinka V, Ulm S, Loy T, Hall J (2002) The genetic speciation of archaeological fish bone: a feasibility study from Southeast Queensland. *Qld Archaeol Res* 13:71–78
- Hoffmann RC (1994) Medieval Cistercian fisheries natural and artificial. In: Pressoure Léon. *L’espace cistercien*, Comité des travaux historiques et scientifiques, Paris, pp 401–414
- Hoffmann RC (1995) Environmental change and the culture of common carp in medieval Europe. *Guelph Ichthyol Rev* 3:57–85
- Hoffmann RC (1996) Economic development and aquatic ecosystems in medieval Europe. *Am Hist Rev* 1013:631–669
- Hoffmann RC (2005) A brief history of aquatic resource use in medieval Europe. *Helgol Mar Res* 59:22–30
- Hüster-Plogmann H (2002) Die Fischreste aus den befestigungszeitlichen Schichten. In: Schwarz PA (ed) *Kastelen 4: Die Nordmauer und die Überreste der Innenbebauung der spätromischen Befestigung auf Kastelen*. *Forsch in August* 24:325–342
- Hüster-Plogmann H (2006) *Fisch und Fischer aus zwei Jahrtausenden. Eine Fischereiwirtschaftliche Zeitreise durch die Nordwestschweiz*. *Forsch in August*, p 39
- Jackson JBC, Kirby MX, Berger WH, Bjornda KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical over fishing and the recent collapse of coastal ecosystems. *Science* 293:629. doi:10.1126/science.1059199
- Jandl M, Mosser M (2008) Befunde im Legionslager Vindobona. Teil IV: Vallum, fabrica und Kasernen in der westlichen retentura—Vorbericht zu den Grabungen Am Hof im Jahr 2007. *Fundort Wien* 11:4–34
- Jones AKG (1983) A comparison of two on-site methods of wet-sieving large archeological soil samples. *Sci Archeol* 25:9–12
- Kühtreiber K (2005) *Burg Dunkelstein, Stadtgemeinde Ternitz (Niederösterreich)—Ergebnisse der archäologischen Untersuchungen eines hochmittelalterlichen Adelsitzes*. *Burgen und Schlösser* 1:48–51
- Kühtreiber K (2006) Archäologische erschließbare Nutzungsräume und -areale in der Burg Dunkelstein, NÖ.—Ein Vorbericht. In: Krenn M, Krenn-Leeb A (eds) *Castrum Bene 8 Burg und Funktion*. *Archäologie. Österreichs Spezial* 2:145–164
- Kunst GK, Galik A (2000) Tierreste aus Kartause Mauerbach als Zeugnisse einstiger Ernährungsgewohnheiten. *Österreichische Z. für Kunst und Denkmalpf.*, LIII 1999Heft 2/3/4:671–681
- Kurlansky M (1999) *Cod*. Vintage, London
- Lampen A (2000) *Fischerei und Fischhandel im Mittelalter*. Matthiesen Verlag, Husum
- Lepiksaar J (2001) Die spät- und postglaziale Faunengeschichte der Süßwasserfische Schwedens. *Oetker-Voges*, Kiel
- Locker A (2001) *The role of stored fish in England 900–1750 AD; the evidence from historical and archaeological data*. Publishing Group Limited, Sofia
- Makowiecki D (2000) *Catalogue of Subfossil Fish Remains from Poland*. *Archaeofauna* 9:133–149
- Makowiecki D (2003) *Historia ryb i rybołówstwa w holocenie na Niziu Polskim w świetle badań archeoichtiologicznych*. Instytut Archeologii i Etnologii Polskiej Akademii Nauk, Poznań
- Morales A, Rosenlund K (1979) Fish bone measurements an attempt to standardize the measuring of fish bones from archaeological sites. *Steenstrupia*, Copenhagen
- Mosser M (2010) Befunde im Legionslager Vindobona. Teil V: Das Intervallum an der westlichen Lagermauer—Vorberichte zu den Grabungen Am Hof in den Jahren 2008/2009. *Fundort Wien* 13:50–74
- Noble RAA, Cowx IG, Goffaux D, Kestemont P (2007) Assessing the health of European rivers using functional ecological guilds of fish communities: standardising species classification and approaches to metric selection. *Fish Manag Ecol* 14:381–392
- Nussbaumer M, Rehazek A (2007) Fish remains from a 16th century noble household in Unterseen, Bernese Oberland, Switzerland. In: Hüster Plogmann H (ed) *The role of fish in ancient time*. Proceedings of the 13th meeting of the ICAZ Fish Remains Working Group in October 4–9, Basel/August 2005, pp 107–112
- Ólafsdóttir GÁ, Westfall KM, Edvardsson R, Pálsson S (2014) Historical DNA reveals the demographic history of Atlantic cod

- (*Gadus morhua*) in medieval and early modern Iceland. *Proc R Soc Lond B* 281/1777. doi:10.1098/rspb.2013.2976
- Orton DC, Makowiecki D, de Roo T, Johnstone C, Harland J, Jonsson L, Heinrich D, Bødker Enghoff I, Lõugas L, Van Neer W, Ervynck A, Hufthammer AK, Amundsen C, Jones AKG, Locker A, Hamilton-Dyer S, Pope P, MacKenzie BR, Richards M, O'Connell T C, Barrett J H (2011) Stable Isotope Evidence for Late Medieval (14th–15th C) Origins of the Eastern Baltic Cod (*Gadus morhua*) Fishery. *PLoS One* 6/11:1–15
- Pauly D (1995) Anecdotes and the shifting baseline syndrome of fisheries. *TREE* 10(10):430
- Pesty F (1867) Magyarország régi vízhálózata (Old water network in Hungary). Századok, I.k.
- Petznik B (2012) Neueste Grabungen in Schloss Petronell 2010–2011. Vorläufige Grabungsergebnisse. *Archäologie Österreichs* 23(2):29–34
- Pitcher TJ (2001) Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecol Appl* 11(2):601–617
- Pucher E (1991) Der frühneuzeitliche Knochenabfall eines Wirtshauses neben der Salzburger Residenz. *Salzburger Museum Carolino Augusteum Jahresschriften* 35/36-1989/90:71–135
- Radke RJ, Petzoldt T, Wolter C (2000) Stability of pharyngeal measures commonly used for reconstruction of prey fish length. *J Fish Biol* 57:961–967
- Radu V (2003) Exploitation des ressources aquatiques dans les cultures néolithiques et chalcolithiques de la Roumanie Méridionale. Thèse docteur de l'Université Aix-Marseille
- Reischl F (1921/1922) Geschichtliche Beiträge zur Ernährungskunde. *Ernährungskunde. Österreichischer Almanach für Ernährung*. 6-12. Salzer, Wien
- Schiemer F, Waibacher H (1998) Zur Ökologie großer Fließgewässer am Beispiel der Fischfauna der österreichischen Donau. *Stapfia/Kataloge des OÖ. Landesmuseums NF* 52/126:7–22
- Schiemer F, Gutí G, Keckeis H, Staras M (2004) Ecological status and problems of the danube river and its fish fauna: a review. In: *Proceedings of the second international symposium on the management of large rivers for fisheries: sustaining livelihoods and biodiversity in the New Millennium*, 11–14 February 2003, Phnom Penh, Kingdom of Cambodia, vol I, no. 16, pp 273–299
- Schmelzl W (1547) Ein Lobspruch der hochlöblichen und weitberühmten Stadt Wien in Österreich. Karl Rauchs Nachfolgern, Wien
- Sommerhäuser M, Robert S, Birk S, Hering D, Moog O, Stubauer I, Ofenböck T (2003) Developing the typology of surface waters and defining the relevant reference conditions. UNDP/GEF Danube Regional Project. Final report
- Spindler T (1997) Fischfauna in Österreich. *Monographien Umweltbundesamt* 87:1–140
- Uhlirz K (1900) Quellen zur Geschichte der Stadt Wien. II. Abteilung Regesten aus dem Archiv der Stadt Wien. Band 2. Wien, Altertumsverein zu Wien
- Van Neer W, Ervynck A (2004) Remains of traded fish in archaeological sites: indicators, or bulk food. In: Jones O'Day S, Van Neer W, Ervynck A (eds) *Behaviour behind bones. The zooarchaeology of ritual, religion, status and identity. Proceedings of the 9th conference of the International Council of Archaeozoology*, Durham 2002, pp 203–214
- Wacha G (1956) Fische und Fischhandel im Alten Linz. *Naturkundliches Jahrbuch der Stadt Linz* 1956:61–68
- Zauner G (1996) Ökologische Studien an Perciden der oberen Donau. *Biosyst Ecol Ser* 9:1–77
- Zauner G (1997) Acipenseriden in Österreich. *Österreichs Fisch* 50(1997):183–187
- Zeiringer J (1991) Nahrung und Speisen im Cisterciensertift Neuberg/Mürz. Inauguraldiss. Geisteswiss. Fakultät Karl-Franzens Univ, Graz
- Zohar I, Belmaker M (2005) Size does matter: methodological comments on sieve size and species richness in fishbone assemblages. *J Am Sci* 32:635–641