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Carbon and nitrogen isotopic ratios in archaeological and modern Swiss fish as possible markers for diachronic anthropogenic activity in freshwater ecosystems

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ABSTRACT

The aim of this study is to investigate isotopic variability in archaeological ($n = 85$) and modern ($n = 29$) freshwater fish specimens from Switzerland. Here, carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratio analysis was performed on bone collagen samples of pike (*Esox lucius*), perch *(Perca fluviatilis)*, barbel *(Barbus barbus)*, roach *(Rutilus rutilus)* and carp *(Cyprinus carpio)* from eleven archaeological (11th to 18/19th centuries CE) and modern sites. The archaeological vs. modern fish data revealed significant isotopic differences for pike, perch and barbel ($\delta^{13}C$ $p \leq 0.03$; $\delta^{15}N$ $p \leq 0.008$), and provides possible evidence for a temporal change in Swiss aquatic ecosystems from Medieval to modern times. In comparison to archaeological fish ($\delta^{13}C$ mean ± SD; −23.3 ± 1.6‰; $\delta^{15}N$ mean ± SD; 8.3 ± 1.8‰), the modern fish samples show decreased $\delta^{13}C$ and increased $\delta^{15}N$ values ($\delta^{13}C$ mean ± SD; −27.4 ± 2.3‰; $\delta^{15}N$ mean ± SD; 12.5 ± 4.1‰) that can be associated with anthropogenic effects: fossil fuel combustion, deforestation and organic waste in the form of sewage and fertilizers. The isotopic signatures of archaeological fish remains indicate a local fishery practice, but also the exploitation of distant fishing grounds and freshwater fish transportation. Furthermore, a diachronic isotopic trend is observed in young perch from sites in Basel, dating between the 12th and 15/16th centuries CE, and the isotopic data from the Rhine freshwater fish (18/19th century CE) suggests that a significant shift in the river's trophic state was possibly caused by organic pollution from urban and industrial wastewater. This retrospective research illustrates possible natural processes and human activities which can cause differences in fish stable isotope data and highlights the ability to elucidate changes in past bodies of water. Furthermore, this study provides an interpretative framework for additional palaeoenvironmental studies and modern restoration projects focused on freshwater ecosystems.

1. Introduction

Stable isotope ratio analysis has become an important tool to examine ecological processes and anthropogenic impact on modern freshwater ecosystems and fish stocks in lakes and rivers (e.g. Macko and Ostrom, 1994; Kendall et al., 2007; Gladyshev, 2009). Past studies have found that freshwater fish carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values of muscle tissue, bone and scales can act as important bioindicators that reflect the ecological water conditions and the input of contaminants (e.g. Harvey and Kitchell, 2000; Lake et al., 2001; Perga and Gerdeaux, 2003; Miller et al., 2010). While it is clear that isotopic studies provide invaluable information about modern ecological processes, only a handful of studies have addressed these topics in prehistoric or historic freshwater ecosystems (e.g. Dufour et al., 1999; Van Neer et al., 2009; Miller et al., 2010; Fuller et al., 2012). Thus, it is still unclear to what extent humans have influenced freshwater fish stocks and aquatic environments in the past. This is especially true for early modern, Medieval and Roman periods, where possible human impact on aquatic ecosystems is assumed to have occurred (e.g. Van Neer et al., 2009).

One approach to evaluate past aquatic environments with archaeozoological material is to reconstruct the species composition of the fish stocks populating a body of water at a specified time. A shift

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from sensitive to more tolerant fish species may indicate a change in water condition (Van Neer et al., 2009; Van Neer and Ervynck, 2010). Indeed, such a decrease in the sensitive freshwater fish species spectra has been detected at numerous archaeological sites of the Rhine drainage basin in Switzerland (Basel, Stein am Rhein, Schaffhausen, Winterthur; c.f. Fig. 1; Häberle et al., 2015). This decline in indicator species including several salmonids (Salmonidae), barbel (*Barbus barbus*) and bullhead (*Cottus gobio*) occurred at minimum, from the 14th to 19th centuries CE and suggests the possibility that there was increased anthropogenic impact on fish and water systems during this time. Although Medieval written records reveal evidence of coeval human interference in Swiss water bodies (Amacher, 1996; Simon-Muscheid, 2006), a further methodological approach, the analysis of stable isotope signatures of freshwater fish, was undertaken here in order to better understand the archaeozoological data. This study was performed on archaeological pike (*Esox lucius*), perch (*Perca fluviatilis*), barbel (*Barbus barbus*), roach (*Rutilus rutilus*) and carp (*Cyprinus carpio*) from sites of the Rhine drainage basin, dating between the 11th–19th centuries CE (Fig. 1). Due to the fact that modern fish isotopic values can detect alterations in water systems (Macko and Ostrom, 1994; Brenner et al., 1999; Lake et al., 2001; Schlachter et al., 2005), a comparison of the archaeological fish isotope signatures with those obtained from modern freshwater fish species from the same region was performed to provide more information about the possible changes in aquatic environments from the Medieval period onwards.

2. Isotopic analysis of archaeological and modern freshwater fish: opportunities and limitations

Many factors can account for the different isotopic signatures of modern and archaeological freshwater fish, and these will be briefly addressed in this section. Variations are caused by spatial (e.g. benthic-pelagic gradients) or temporal differences (e.g. seasonal shifts) in aquatic ecosystem as well as by differences in fish feeding habits and fish habitats, a change in primary production levels or even by organic pollution (c.f. Cabana and Rasmussen, 1994; McClelland et al., 1997; Lake et al., 2001; Vander Zanden and Rasmussen, 1999; Grey et al., 2000; Perga and Gerdeaux, 2003; Schlachter et al., 2005; Gu et al., 2011; Miller et al., 2010; Morrissey et al., 2012; Thibodeau et al., 2013). Several studies on modern fish confirm the relationship between ^{15}N-enriched values and the input of organic pollutants like sewage and fertilizers that change the trophic state or condition of the water (Macko and Ostrom, 1994; Brenner et al., 1999; Lake et al., 2001; Schlachter et al., 2005). For archaeological fish, the exploration of anthropogenic pollution in past aquatic ecosystems with stable isotope analysis is a promising avenue of research, when combined with available historical records, archaeological and archaeoichthyological information (e.g. Van Neer et al., 2009; Miller et al., 2010; Fuller et al., 2012).

Other factors influencing δ^{15}N values in both modern and archaeological fish, are age and size related trophic level effects (e.g. DeNiro and Epstein, 1978; Schoeninger and DeNiro, 1984; Hansson et al., 1997; Szpak et al., 2012; Häberle et al., 2016). These effects can result in higher mean δ^{15}N values of the larger and older fish specimens. Furthermore, the comparison of specimens with similar or identical niches from different water bodies can be complicated by the fact that water systems have specific isotopic signatures due to differences in δ^{13}C and δ^{15}N inputs (c.f. Fry and Sherr, 1984; Finlay and Kendall, 2007). Disentangling these various factors presents a major challenge for modern and even more so for archaeological data. These problems are enhanced by the fact that studies of archaeological samples are limited by the availability of the archaeological record. Degradation and contamination is another common problem with archaeological fish remains (e.g. Szpak, 2011; Fuller et al., 2012, Häberle et al., 2016). In addition, even if the dating and location of the presented archaeological sites are well defined, determining freshwater fish provenance at archaeological sites is more difficult in comparison to modern fish, because specimens could originate from either local waters or have been transported from distant fishing grounds. For example, a historical source from the 12th century CE describes the transportation of whitefish from Lake Lucerne to Basel (about 110 km) by the order of the Provost of Basel (Müller, 1989). Additionally, some species could even come from fish ponds (especially carp, other cyprinids and pike) due

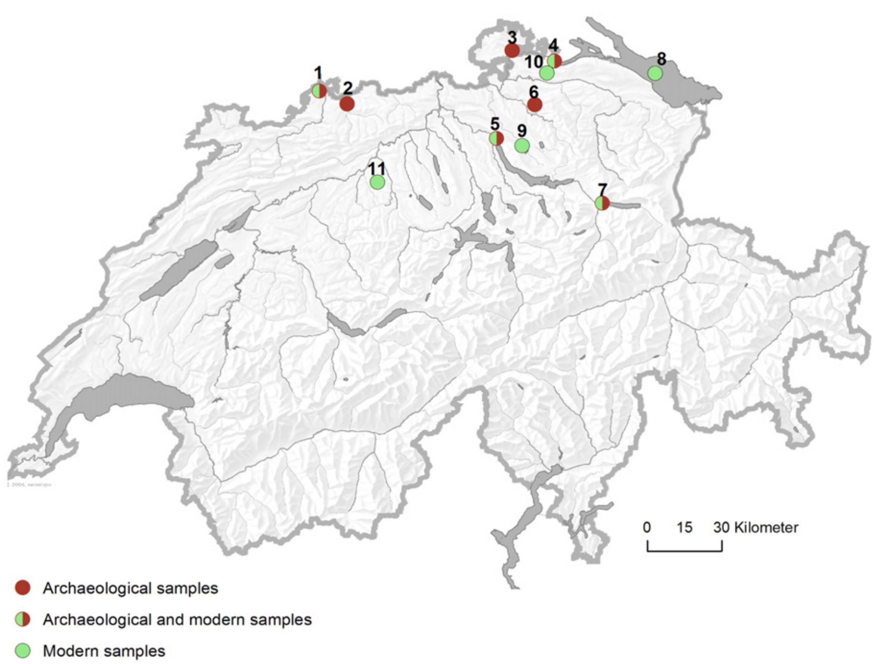

Fig. 1. Map of Switzerland with sites sampled in this study. Archaeological fish samples come from the following sites: 1 = Basel, Canton Basel-Stadt (5 sites); 2 = Füllinsdorf, Canton Basel-Landschaft (1 site); 3 = Schaffhausen; Canton Schaffhausen (1 site); 4 = Stein am Rhein, Canton Schaffhausen (1 site); 5 = Zürich, Canton Zürich (1 site); 6 = Winterthur, Canton Zürich (2 sites); 7 = Weesen, Canton St. Gallen (1 site). Modern fish samples come from the following locations: 1 = Rhine, Basel, Canton Basel-Stadt; 4 = Rhine, Stein am Rhein; Canton Schaffhausen; 5 = Lake Zürich, Zürich, Canton Zürich; 7 = Lake Walen, Weesen, Canton St. Gallen; 8 = Lake Constance; Altenrhein, Canton St. Gallen; 9 = Lake Greifen, Maur and Schwarzenbach, Canton Zürich; 10 = Lake Nussbaum, Canton Thurgau; 11 = Two artificial fish ponds in Pfaffenau, Canton Luzern and in Brittnau, Canton Aargau.