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The fish of Lake Titicaca: implications for archaeology and changing ecology through stable isotope analysis

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ABSTRACT

Research on past human diets in the southern Lake Titicaca Basin has directed us to investigate the carbon and nitrogen stable isotopes of an important dietary element, fish. By completing a range of analyses on modern and archaeological fish remains, we contribute to two related issues regarding the application of stable isotope analysis of archaeological fish remains and in turn their place within human diet. The first issue is the potential carbon and nitrogen isotope values of prehistoric fish (and how these would impact human dietary isotopic data), and the second is the observed changes in the fish isotopes through time. Out of this work we provide quantitative isotope relationships between fish tissues with and without lipid extraction, and a qualitative analysis of the isotopic relationships between fish tissues, allowing archaeologists to understand these relationships and how these values can be applied in future research. We test a mathematical lipid normalization equation to examine whether future researchers will need to perform lipid extraction procedures for Lake Titicaca fish. We also analyze a number of aquatic plants to better understand the range of isotopic signatures of the Lake Titicaca ecosystem. We use these data to better understand prehistoric human diet and the role that fish may have played in the past as well as potential changes in local lake ecology through time.

1. Introduction

This study grew out of the rich yet complex study of prehistoric diets, including stable isotope data from cooking pots, plants, animals and human teeth that have been collected by the Taraco Archaeological Project working in the Titicaca Basin of Bolivia. Here we present stable isotope analysis of the archaeological fish samples to understand their role in the diet of the Formative Period inhabitants of the southern Lake Titicaca Basin. Carbon and nitrogen stable isotope analysis has become very useful in a variety of dietary studies (Ambrose, 1993; Finlay et al., 2002; Schoeninger and DeNiro, 1984), and ancient human diets and their change through time (Ambrose et al., 1998; Hastorf, 1991; Katzenberg et al., 1995; Prowse et al., 2004; Richards et al., 2003; Rutgers et al., 2009; Schwarcz et al., 1985; Van Klinken et al., 2000; White et al., 1999). However, in order to place the fish in human history, it is necessary to learn about the relationships and ecology of the fish from their muscle, bone and scales, since muscle is rarely preserved in archaeological contexts, whereas bone and scales are. We investigate modern fish specimens from Lake Titicaca to compare with our archaeological analysis. Studying fish through isotopic analysis introduces an additional layer, as recent research has highlighted the important role that lipid extraction plays in retrieving correct $\delta^{13}C$ signatures from samples that contain lipids (Kojadinovic et al., 2008; Mintenbeck et al., 2008; Post et al., 2007; Sotiropoulos et al., 2004; Sweeting et al., 2006).

In this paper we contribute to the discussion of two related issues regarding the application of stable isotope analysis to archaeological fish remains and in turn their place within human diet. The first issue is the interpretation of the carbon and nitrogen isotopic values of prehistoric fish (and how these impact human dietary values), and the second is the lake–fish ecological relationship. By understanding the isotopic compositions of the fish within the larger ecology of Lake Titicaca we can better understand the human interactions in this rich and diverse region as well as the roles that fish played in human life on the Taraco Peninsula during their first 1000 years of living in settled communities. To address these two questions, we first examine modern fish and the effects of lipid extraction on carbon and nitrogen isotope values. Then we turn to the isotopic relationships between the muscle, bone, and scale tissues of modern fish to learn of their variance. The fish and aquatic plants of Lake Titicaca have not previously been analyzed

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for their isotope compositions and previous studies of aquatic environments show large variation in the isotopic ranges observed (Chisholm et al., 1982; Dufour et al., 1999; Fischer et al., 2007; France, 1995; Katzenberg and Weber, 1999; Mintenbeck et al., 2008; Sotiropoulos et al., 2004; Sweeting et al., 2006). Other studies of modern and archaeological fish species from lacustrine environments have reported a large range of carbon values. France (1995) reported pelagic consumers to range from δ^{13}C −38 to −26‰ and littoral consumers to have δ^{13}C values from −32 to −16‰. Katzenberg and Weber (1999) report fish from Lake Bikal to have δ^{13}C values ranging from −24.6 to −12.9‰. Dufour et al. (1999) report δ^{13}C values for 3 European lakes and Lake Bikal to range from −32.5 to −19.8‰. These carbon values span such a large range that it was clear to us that Lake Titicaca fish need to be investigated in their own right. Finally, we compare modern and archaeological organic carbon and nitrogen isotopes of the fish, providing new information in the foodways scholarship where fish are a potential component.

Lake Titicaca is located at an elevation of 3810 m above sea level in the south central Andes of South America. The lake covers a surface area of approximately 8400 km^2 and is divided in two unequal parts; the northern portion, known as Chucuito is larger and deeper than the southern portion, known as Wiñaymarca (Fig. 1). The Taraco Peninsula, our study area, is located in the southeastern portion of Wiñaymarca. Due to its overall shallowness, Wiñaymarca can support higher biomass densities than the northern portion, but it is also more vulnerable to climatic and environmental changes (Abbott et al., 1997; Baker et al., 2005, 2009; Binford et al., 1997; Calaway, 2005).

Faunal resources are readily available on the shoreline of the Taraco Peninsula and include over 50 species of small to large aquatic and terrestrial birds, two dozen species of fish, and a few species of frogs and toads (Dejoux and Iltis, 1992; Kent et al., 1999; Levieil and Orlove, 1990; Orlove 2002; Portugal Loayza, 2002; Steadman and Hastorf, in press;). In addition, readily available water from a number of streams and associated wetlands (known as bofedales) are ideal habitats for terrestrial vertebrates, including camelids, deer, and several rodents.

Two genera of fish (*Orestias* and *Trichomycterus*), comprising approximately 26 species, have been documented to live in Lake Titicaca (Lauzanne, 1992; Parenti, 1984; Sarmiento and Barrera, 2004). The genus *Orestias* is composed of a wide variety of species most of which are small, rarely exceeding 5 cm in length, some ranging to just above 20 cm of standard length, exhibit high genetic diversity, and are specialized to specific microhabitats within the lake (Lüssen et al., 2003; Parenti, 1984; Vaux et al., 1988). Two species of bottom-dweller filter feeder *Trichomycterus* have been described for Lake Titicaca: *T. dispar* and *T. rivulatus* and they range in size from 12 to 19 cm standard length (Fernández and Vari, 2009; Sarmiento and Barrera, 2003).

Orestias have been known to consume a broad spectrum of aquatic resources including algae, macrophytes, zooplankton, amphipods, ostracods, insects, and insect larvae (Lauzanne, 1992). Their diet is constrained by a number of factors including species, ontogeny, size, availability, and degree of specialization (Vaux et al., 1988). Lauzanne (1992) among other ichthyologists have suggested that *Orestias* specimens tend to eat more fauna as they get larger. *Trichomycterus* are filter feeders ingesting organic remains in

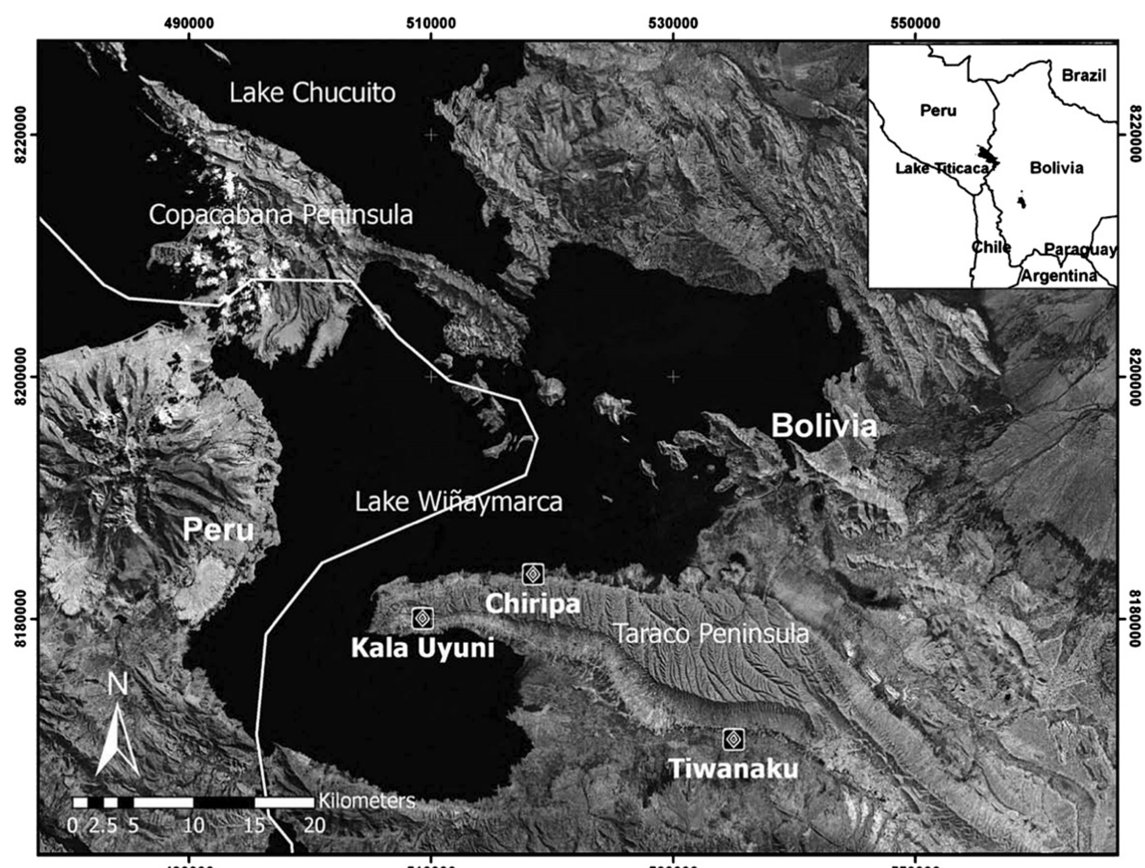

Fig. 1. Map of the region with sites mentioned in text plotted using ArcGIS 9.2. The base image is a Landsat L7 satellite image type Enhanced Thematic Mapper Plus (ETM+) panchromatic Band 8.