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Fishing and environmental change during the emergence of social complexity in the Lake Titicaca Basin

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Abstract: The Lake Titicaca Basin is one of the regions in the world where both primary village and state formation occurred in prehistory. Although agriculture has been discussed as the central engine fueling these processes, fish and other aquatic resources were significant but little-understood components of the region's ancient economy. In this paper, we use zooarchaeological analysis of faunal remains from 367 flotation samples recovered from five archaeological sites to discuss the interplay between fishing, environmental change, and the emergence of sociopolitical complexity in the Taraco Peninsula of Lake Titicaca. Our results suggest that fishing comprised a significant component of the local inhabitants' diet between 1500 BC and 1100 AD. The intensity of fish procurement, however, varied through time and independently of both climatic and population change. We interpret variation in fish consumption through time as a product of group and individual decisions to optimize resource use in a context of dynamic environmental and sociopolitical variability.

Cover Letter

Arica, February 12th, 2014

Dr. John O'Shea
Editor
Journal of Anthropological Archaeology
Emerson F. Greenman Collegiate Professor of Anthropology and
Curator of Great Lakes Archaeology in the Museum of Anthropology
University of Michigan
An Arbor, MI 48109

Ref.: Resubmission of manuscript YJAAR-D-13-00111.

Dear Editor,

Thank you for your comments and revisions regarding our paper "Changing fish exploitation intensity during the emergence of social complexity in the Lake Titicaca Basin" that my co-authors, Katherine M. Moore, Alejandra I. Domic, Chrisinte A. Hastorf, and I submitted to the *Journal of Anthropological Archaeology*. We have incorporated all of the suggestions made by you and the reviewers as well as improved a few additional sections of the paper as presented in the Response to Reviewers statement.

Thank you for considering the paper for publication and I look forward to hearing you soon.

Sincerely,

Capriles

José M. Capriles

Response to Reviewers

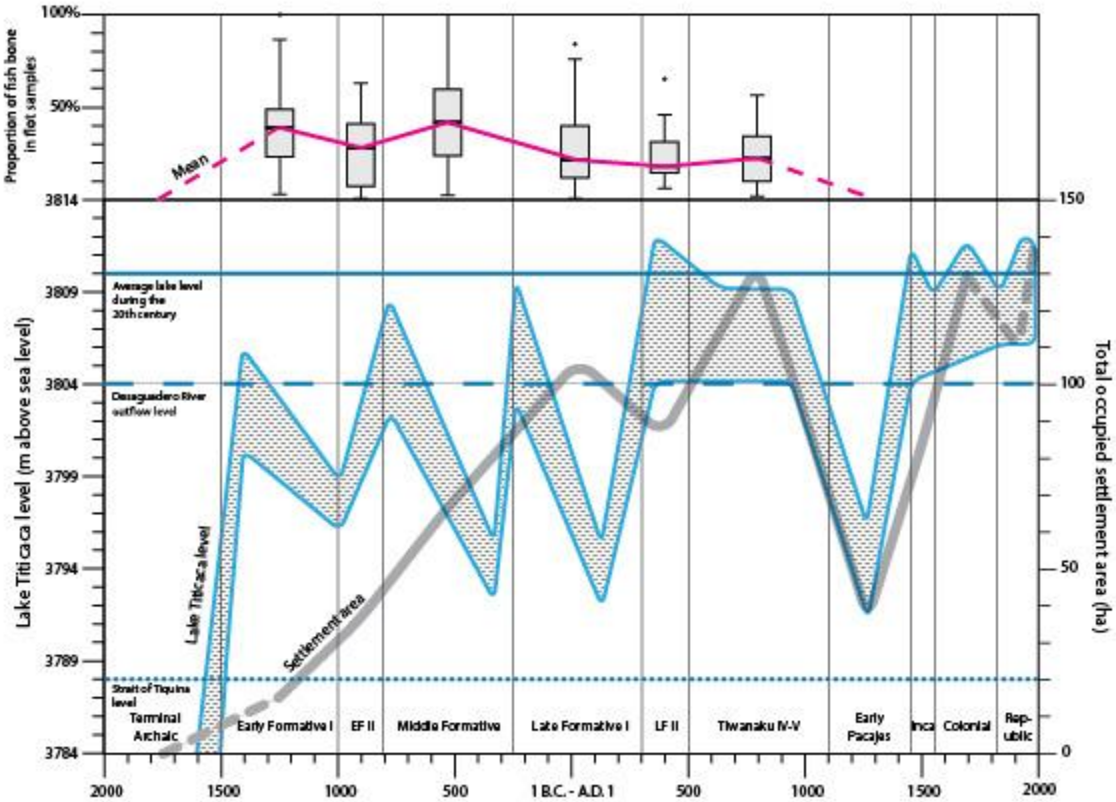
We have found all the suggestions productive and have taken the time to adequately address all of them. Specifically, we have made the following revisions:

1. As suggested by Reviewer 1 and Reviewer 2, the second author reworked the vocabulary and expressions used throughout the manuscript.
2. As suggested by Reviewer 2 we have provided a little more background for readers not familiar with the Andean region.
3. We have improved the links between our data and our models. We have restated our four hypothesis and then improved the discussion to directly address those hypotheses. Although, as Reviewer 1 noted, we could do more with our data, with have limited our discussion and interpretations to the evaluation of these hypotheses and the discussion of the emergence of fishing specialization to keep the paper concise and on point. In doing this we have clarified the connection between other economic activities such as cultivation and animal husbandry as suggested by Reviewer 1.
4. As suggested by Reviewer 1 we have changed the conclusions heading to "Final thoughts".
5. Following Reviewer 1 we changed the abstract to mention "several" instead of "few" societies several regions of the world where village and state formation occurred.
6. We have improved the Materials and Methods section so that the sample size and other aspects of our study are clearly laid out (also see Table 1).
7. Given the small number of samples available for some sites during certain periods we have been cautious not to over-interpret our results as well as rely on our quantitative analyses, which control for comparisons between uneven sample sizes.
8. Finally, we have edited the title of the paper and propose "Fishing and environmental change during the emergence of social complexity in the Lake Titicaca Basin" as included in the revised version of the manuscript.

Highlights

- Reviews archaeological research regarding aquatic resource exploitation in Lake Titicaca.
- Data analysis of 367 flotation samples collected from five archaeological sites occupied during six chronological periods between 1500 BC and 1100 AD in the Taraco Peninsula, Bolivia.
- Evaluates hypotheses regarding how fish utilization varied in relation to environmental (lake-level) and demographic fluctuations.
- Discusses models for explaining the development of fishing intensification.

Graphical Abstract



Fishing and environmental change during the emergence of social complexity in the Lake Titicaca Basin

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(DO NOT CITE WITHOUT PERMISSION OF THE AUTHORS)

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Abstract

The Lake Titicaca Basin is one of the regions in the world where both primary village and state formation occurred in prehistory. Although agriculture has been discussed as the central engine fueling these processes, fish and other aquatic resources were significant but little-understood components of the region's ancient economy. In this paper, we use zooarchaeological analysis of faunal remains from 367 flotation samples recovered from five archaeological sites to discuss the interplay between fishing, environmental change, and the emergence of sociopolitical complexity in the Taraco Peninsula of Lake Titicaca. Our results suggest that fishing comprised a significant component of the local inhabitants' diet between 1500 BC and 1100 AD. The intensity of fish procurement, however, varied through time and independently of both climatic and population change. We interpret variation in fish consumption through time as a product of group and individual decisions to optimize resource use in a context of dynamic environmental and sociopolitical variability.

Keywords: economic organization, environmental change, fish, social complexity, zooarchaeology.

Introduction

Aquatic resources have had a preeminent role in facilitating population growth, sedentism, and economic specialization in many coastal regions of the world due to their nutrient density, abundance and predictability (Campbell and Butler 2010; Casteel 1977; Colley 1990; Erlandson and Rick 2008; Habu et al. 2011; Morales-Muñiz and Roselló-Izquierdo 2008; Wheeler and Jones 1989). Communities focused on exploiting fish and shellfish often developed along marine continental shorelines and islands, but evidence of shell mounds and fishing settlements are also common in interior rivers and lakes around the world. For instance, along the Pacific Coast of western South America the exploitation of marine resources supported specialized sedentary communities as early as the mid-Holocene (Marquet et al. 2012; Moseley 1975, 1992; Reitz 2001; Reitz and Sandweiss 2001; Richardson 1998; Sandweiss 2008) and fishing was essential for almost every settled society in the Amazon (Erickson 2000, 2008). Although there is increasing interest concerning the organization and environmental context of fishing economies in prehistoric societies, there is less systematic study of the ecological impact of fishing, the archaeology of fishing technology and the integration of fishing and fishing communities into broader political economies (Barrett et al. 1999, 2004; deFrance 2009; Orlove 2002). These aspects of fishing are particularly important in regions where fishing was one of several economic practices that could have been intensified under particular social, economic, and environmental conditions.

Located in the south central Andes, the Lake Titicaca Basin is renowned as the setting for two fundamental primary processes of social evolutionary change beginning with early village formation starting 3500 years ago. The type site for early villages in this region, Chiripa, is one of the sites in this study (Bandy 2006; Browman 1989). Roughly 1500 years ago, the region also saw the emergence of the Tiwanaku state, centered on the monumental site of Tiwanaku, 15 km southwest of Chiripa, but with an influence extending as far as the Pacific coast and the warmer flanks of the Andes (Hastorf 2008; Janusek 2008; Stanish 2003). Archeologists working in this region have focused on agricultural intensification and camelid pastoralism as primary factors in the cultural evolution of the region including the eventual emergence of the Tiwanaku state (500-1100 AD) (Janusek and Kolata 2004; Kolata 2003; Stanish 2003). We note that the marshlands and aquatic resources of Lake Titicaca have been underestimated in models of social and political change. Detailed studies of fish remains have been limited by the costs of systemic recovery and the absence of baseline research on the zooarchaeology of fish (Capriles 2006; Capriles et al. 2008; Moore 2011). Consequently, few studies have been able to measure the importance of fishing in this region or the contribution of aquatic resources to the processes of regional social change. Yet, historical and ethnographic sources emphasize the importance of aquatic resources in the economy of the people that have traditionally inhabited the shores of Lake Titicaca (Levieil and Orlove 1991; Orlove 2002; Portugal Loayza 2002; Wachtel 2001). For instance, the Uru are often depicted as a fishing specialist group settled on the shores and islands of the Titicaca Basin. However, the origin and antiquity of fishing specialization in the region has not been systematically addressed though it could go back into the Formative Period. In this paper, we use recent research to assess the changing role of fish exploitation in the Taraco Peninsula, Bolivia.

The Taraco Archaeological Project has focused on the cultural processes and environmental context associated with the emergence of social complexity in the Taraco Peninsula (Bandy and Hastorf 2007; Hastorf 2003, 2005; Hastorf and Bandy 1999; Hastorf et al. 2001). The project included systematic survey of 85 km^2 and stratigraphic excavations at five sites (Bandy 2001). The zooarchaeological component of the project sought to reconstruct the economic organization of animal husbandry, hunting, and fishing (Moore et al. 1999, 2010). Faunal remains from Formative components showed that wild resources, particularly fish (*Orestias spp.* (killifishies) and *Trichomycterus* (catfish)), were significant components of the local diet, complementing meat from domesticated (*Lama glama*, *Vicugna pacos*) as well as wild camelids (*Lama guanicoe*, *Vicugna vicugna*) (Capriles et al. 2008; Moore et al. 1999). In addition, we recognized bone tools associated with the manufacture of nets and fishing gear (Moore 1999, 2011, 2013). In this paper, we consolidate data regarding the changing role of fish exploitation and relate it to broader processes of environmental and socio-political change. We use zooarchaeological data to address three questions: 1) how did the organization and intensity of fishing change in relation to population growth and increased social complexity? 2) How did fishing procurement and consumption respond to lake-level fluctuations? 3) How was fishing integrated into the increasingly complex agricultural landscape?

Paleoenvironmental context

Situated at 3810 m above sea level, Lake Titicaca has experienced significant environmental change during the Holocene (Figure 1). Because of its high elevation, Lake Titicaca is less productive than most large tropical lakes but in contrast to most temperate lakes, its productivity does not plunge seasonally (Lewis 1990; Richerson et al. 1986). Lake Titicaca covers a surface area of 8200 km^2 and is roughly divided into two parts; the northern portion (Lake Chucuito) is larger and deeper than the southern portion (Lake Wiñaymarka). Lake Wiñaymarca supports higher primary biomass densities than Lake Chucuito and has the largest littoral zones (as a percentage of total surface area) of the great lakes of the world (Vadeboncoeur 2011). Because the southern profile is so shallow, it responds more quickly to changes in rainfall and temperature than the northern lake. In addition, climatic fluctuations can cause rapid change in the productivity of its subaquatic vegetation and fauna (Dejoux 1992). Fluctuations in the lake's depth and the length of its shoreline influenced regional processes of cultural change (Abbott et al. 1997; Binford et al. 1997; Kolata 2003).

Multiple paleoenvironmental proxies agree that the shoreline of Lake Titicaca fluctuated significantly during the last 15,000 years (Abbott et al. 1997, 2003; Baker et al. 2005; Cross et al. 2001; Rowe et al. 2003). For most of the late Pleistocene the lake's surface was considerably lower and its water more saline than modern conditions. During the early Holocene, increased precipitation drawn from the Amazonian lowlands coupled with glacial runoff raised the lake level enough to trigger outflow through the Desaguadero River. However, during the mid-Holocene, this trend was reversed, flow into the Desaguadero ceased, and the lake was rapidly reduced to a few shallow pools at its deepest portions. Between 4000 and 3500 years ago the mid-Holocene dry period ended with the rapid rise of Lake Wiñaymarka (Abbott et al. 1997).

Compared with the lake level history of the previous 15,000 years, the last 3000 years seem to have been characterized by relative stability with only minor fluctuations between 3000 and

2000 years ago, as Lake Titicaca approached its late Holocene stable level (Cross et al. 2000). Lake levels fluctuated more in the southern basin, including around the Taraco Peninsula which is the focus of this study. There were at least four cycles of lake-level transgression and regression between 1500 BC and 1100 AD (Abbott et al. 1997). Nevertheless, Calaway (2005) observed that the ice-core data from the Quelccaya glacier do not match the data for high and low lake levels and may indicate a more dynamic and recursive pattern of climatic cyclical change (Thompson et al. 2000, 2006). Few studies have recognized how these fluctuations affected the productivity of resources likely to have been used by humans. Our initial hypothesis is that fishing was an important economic activity for the inhabitants of the peninsula, and that fishing may have varied in intensity as a function of resource availability and environmental degradation.

Sociopolitical context

The evidence of aquatic resource exploitation in Lake Titicaca correlates with the appearance of fully sedentary agricultural village societies featuring camelid pastoralism, pottery production, and complex ritual life (Hastorf 2008; Janusek 2008). Although the domestication of camelids, tubers and chenopods were long-term developments, the archaeological record of the region points to a sharp change in human settlement and subsistence between the Terminal Archaic and subsequent Formative periods (Aldenderfer 2009; Capriles and Albarracin-Jordan 2013). The Terminal Archaic (3000-1500 BC) was characterized by mobile foraging whereas the Early Formative I (1500-1000 BC) is marked by the establishment of the first village societies in the region (Bandy 2001). This transition also coincides with the progressive infilling of Lake Wiñaymarka (Hastorf 2008). Village communities used both wild and domesticated plant and animals. By the Early Formative II (1000-800 BC), the peninsula witnessed the construction of trapezoidal sunken courts that included specialized structures and burials associated with community or village-level ceremonial practices that included feasting (Beck 2004; Hastorf 2003, 2008). As the first sedentary villages were established, settlements began to increase in size and internal complexity, in tandem with increasingly intensive agricultural and herding practices (Bruno 2014; Moore 2011; Whitehead 2007). Processes of village growth and fissioning, possibly related to scalar stress but also to declining environmental suitability began during the Early Formative II and continued in subsequent periods (Bandy 2004).

By the Middle Formative (800-250 BC) there is evidence for a two-tier settlement hierarchy, increased inter-regional trade, material wealth, and possible social differentiation (Bandy 2005). The first multi-community polities were organized during the Late Formative I (250 BC –300 AD) when a few settlements, such as Kala Uyuni, grew exponentially and may have secured political control over the entire peninsula for the first time (Bandy and Hastorf 2007). The pastoral economy of the region reflects herds kept for multiple goals (wool, meat, and transport) (Moore 2011) and an increasingly intensive system of cultivation of tubers and cereals (Bruno 2014). A state-level society emerged in the neighboring valley of Tiwanaku at the end of the short and poorly understood Late Formative II (AD 300-500). At the same time, the Taraco peninsula experienced the first and only population decline of this sequence. The state of Tiwanaku during its classic (Tiawanku IV) and expanding (Tiwanaku V) stages included a cycle of consolidation, growth, and eventual disintegration, which lasted approximately 600 years and was associated with an outburst of new economic, social, political, and ideological institutions

(Albarracin-Jordan 2007; Kolata 2003; Janusek 2008). Landscape-scale raised-field agriculture in the neighboring Katari Basin and selected portions of the Taraco Peninsula has been associated with the state's growing population and political economy (Janusek and Kolata 2004; Kolata 2003; Stanish 2003). With the notable exception of the Late Formative II, Bandy (2001) has documented steady population growth in the Taraco Peninsula between the beginning of the Formative Period and the consolidation of the Tiwanaku state.

Throughout this time, fish consumption could have been increasingly embedded within the growing prestige political economy if fish had cultural status (Stanish 2001, 2003). In the same way that meat and other high-value foods may have been controlled, emerging elites could have increasingly regulated the exploitation, distribution, and consumption of fish, particularly in regional administrative centers. Alternatively, increased fish consumption could have occurred as part of voluntarily contributed food offerings during local work parties and feasts. Still another scenario is that there would have been no political or symbolic control over the harvesting and consumption of fish, with fish remaining as a resource that individuals collected on their own. Interestingly enough, iconographic representations of various zoomorphic depictions of both *Orestias* and *Trichomycterus* genera have been documented on Formative and especially Tiwanaku monumental architecture as well as on ceramic vessels and textiles (Figure 2) (Smith and Pérez Arias 2013; Posnansky 1945). Ichthyomorphic motifs are frequent on some of the most iconic stone sculptures at Tiwanaku (such as the Gateway of the Sun or the Gateway of the Moon), suggesting that the meaning of fish went beyond a mere food item. The symbolic status of fish could have originated in the emblematic identity of certain specialized fishing communities but also in the collective recognition of the importance of Lake Titicaca and its resources.

In accord with the sociopolitical development documented in the Lake Titicaca Basin we propose four complementary hypotheses for explaining sustained fishing intensity over time and the possible emergence of fishing specialization.

1. Fishing intensification could have occurred as a function of increasing demand for staple resources, modulated by environmental constraints such as the fluctuation in the lake-levels (and the climatic processes that produced these changes). In this case, we would expect to see fishing decline in periods of lower lake levels and increase when the lake level rose.
2. Fishing specialization could have increased as a result of individual decisions made at the local level. Such decisions to engage in fishing might have been driven by the desire to exchange fish with communities that had limited access to lake resources. Fish would have been a preferred local food, mostly procured and consumed by shoreline communities. In this case, we would expect to see local differences in the intensity of fishing, continued intensity of fish use during times of declining lake conditions, and deposition of fish remains in contexts associated with other high value foods.
3. Fishing importance was impacted by the rise of the state at Tiwanaku. In a similar manner to the centralization hypothesized for raised-field agriculture; fishing, too, might have been increasingly regulated by the center, resulting in an increasing need for fish as a tribute and exchange commodity. In this case, fishing would have intensified during increased influence by the important regional center.

4. A final hypothesis suggests that fishing would be intensified during times of environmental uncertainty. Poor local harvests and drought would encourage people to exploit aquatic resources as fallback foods. Therefore, fishing (along with hunting birds and collecting eggs) could have been intensified in times of political or environmental hazard as a small-scale risk minimization strategy.

We will evaluate these hypotheses and their expectations using fish remains recovered by intensive and systematic excavations of the Taraco Archaeological Project.

Materials and methods

Fish have been generally recognized as an important resource for the prehistoric people of the Titicaca region (Bennett 1936; Kent 1982), but the methods used to study fishing have been unsystematic. We extend previous methodological approaches (Capriles et al. 2007, 2008; Miller et al. 2010; Moore 2011; Moore et al. 1999, 2010), basing our interpretations exclusively on remains recovered from heavy fractions from water flotation rather than standard excavation screens. Earlier work had established that even relatively fine mesh screens (1/4 inch or 6.35 mm) could not provide an unbiased sample of fish bones, given the small body size of the fish themselves (Moore et al. 1999). We collected and analyzed flotation samples from all excavated contexts including middens, trash pits, construction fills, and occupation floors as well as sterile deposits and off-site controls. Although deposits have different depositional histories and were exposed to diverse taphonomic processes, preservation of faunal remains is, in general, very good; and by grouping different contexts together we can produce time-averaged samples that aggregate some of the contextual diversity. For instance, some of the deposits densest in fish bones were pit fills in which fish were apparently associated with offerings or ritual meals (Capriles 2006). When we sampled deposits beyond the borders of known sites, those samples also contained a few fish bones and scales, reflecting the persistence and ubiquity of fishing over long periods.

Water flotation was carried out using a modified SMAP machine that processed approximately 10 l sediment samples with a gentle flow of water powered by a small gasoline pump (Bruno 2008; Bruno and Whitehead 2003; Hastorf and Bandy 1999). Two fractions were recovered, a light fraction, composed primarily of carbonized plant remains; and a heavy fraction, which was collected on an insert lined with 0.5 mm metal mesh. Although fish bones and scales were occasionally recovered from light fractions, our study relies entirely on the remains recovered on the heavy fractions. The heavy fractions were sorted in the field into broad artifact and ecofact categories. In the laboratory, the animal bones were sorted into general taxonomic categories: large mammals (mostly composed of camelid bone fragments), small mammals (mostly rodents of various sizes), birds (more than 20 genera of aquatic and terrestrial birds), herpetofauna (a few species of reptiles and amphibians), fish bone and scales, bird eggshell, and gastropod shell. Burned and unburned materials were separately weighed for each category, and the samples were scored for weathering and erosion (Moore et al. 2010). The fish were dominated by *Orestias* spp. but also included a few *Trichomycterus* spp.) (Parenti 1984; Vaux et al. 1988). These taxonomic categories were quantified by weight for each flotation sample, using a digital scale sensitive to 0.01 gm. In various analyses, as appropriate, we have expressed the quantities of vertebrate remains as densities (amount by weight/volume of sediment) and as relative weight (proportions).

The sample discussed here comes from 367 flotation heavy fractions recovered from five archaeological sites on the Taraco Peninsula (Kala Uyuni, Chiripa, Sonaji, Kumi Kipa, and Iwawi) occupied during six successive chronological periods (Table 1). Detailed element identifications of fish remains were made by Capriles (2006) for 31 of these samples. We used these detailed data to explore the relationship between fish bone counts (NISP), minimum number of individuals (MNI) and weight, and to subsequently estimate proportion of taxa and density of fish remains based on bone weights alone.

Our analysis explored temporal and spatial trends and evaluated those trends with inferential statistics. To model the relationship between fish NISP, MNI and weight, we used Spearman's correlation coefficient (r_s) (Lyman 2008). To estimate fishing intensity and its change through time we tested differences in taxonomic proportions (identified as relative weight of the constituents of individual flotation samples) and density (g/l) by site and between periods using one-way analysis of variance (ANOVA) followed-up by Tukey's HSD post-hoc tests to identify significant differences within groups. One-way ANOVAs and post-hoc tests were used to test for differences in fish relative proportion and fish density among sites occupied during the same period.

Results

Fish bone weight as a quantification unit

We analyzed the relationship between NISP, MNI, and weight using detailed element identification from 31 flotation samples from Formative cultural contexts recovered at the site of Kala Uyuni. This step allowed us to show that fish bone weight could be a representative and useful quantitative measure (Capriles et al. 2008:Table 1). The fish identified in this set of samples included *Orestias* (ranging from 91.7 % to 93.1% of fish bone samples by bone weight across the Formative) and *Trichomychterus* (8.3% to 6.9%). Multiple species of *Orestias* were inferred from size variation and from observations of the surface textures on scales (Capriles 2006). We found strong and highly significant linear relationships between weight and both NISP and MNI (NISP vs. weight, r_s=0.986, p<0.001, MNI vs. weight, r_s=0.94, p<0.001) (Figure 3). In fact, the correlations between NISP and MNI vs. weight were higher than the NISP vs. MNI correlation (r_s=0.938, p<0.001, which was also highly significant). The small body size of the individual fish and the apparent culinary practices of serving fish whole strengthen the approach of using weight as a direct measure of abundance. In a few cases, the interdependence of these variables was reduced due to fragmentation from weathering and soil compression. However, given the strong relationship between all quantification units and their known interdependence, weights from flotation heavy samples are useful measure of taxonomic proportion and density. We used the proportion of fish remains to other vertebrate classes to provide estimates of the relationship of fish to other animal resources. We used fish density as a relative measure of fish discard in different cultural contexts. Interestingly, relative proportion and density of fish remains among all samples (Figure 4) suggest a low but statistically significant correlation (r_s=0.431, p<0.001).

Proportion of fish to other taxa

Fish remains were abundant during all periods and in all sites, comprising between 23% and 43% of the animal bone by weight (Figure 5a, Table 2). This ubiquity and high proportion of fish is an initial indication of how important fishing must have been to the people in the Taraco Peninsula. The proportion of fish remains varied significantly between periods however, decreasing slightly through time (one-way ANOVA F=7.7, $p<0.001$). At Chiripa, the mean proportion of fish remains during the Early Formative I was 38±3, with 39±2 in the Middle Formative. Both these values are significantly higher than during the Early Formative II, between these two time periods (24±4; one-way ANOVA F=8.5, $p<0.001$) (see also Moore 2011). At Kala Uyuni, the fish proportion was two to three times higher during Middle Formative (56.1±4 of all taxa) than during all the subsequent periods at that settlement, including Late Formative I and II (one-way ANOVA F=7.05, $p<0.001$). The Middle Formative fish proportions at Kala Uyuni were markedly higher than fish proportions at Chiripa during the same period (Table 3), suggesting that fish remained a much more important part of the diet at Kala Uyuni overall (One-way ANOVA F=24.6, $p<0.001$). At Sonaji, no significant chronological changes were observed during the Late Formative I, though Sonaji exhibited 1.7 times higher relative proportion of fish remains than at Kumi Kipa, its near neighbor (One-way ANOVA F=2.9, $p=0.06$).

Fish density

Though variation between different contexts in each site is high, the density of fish remains was regular in many contexts. We observed a relatively wide range of fish bone densities between repeated samples from some single contextual units, typically from secondary fill and midden. This indicates that the discard of fish bones must have been episodic and discrete, and that the long-term trends that we discuss here are in large part the result of persistent but small-scale fish use. Thus, the averages we cite for various time periods best capture the long-term patterns. The patchy distribution also indicates that fish bones are largely in place within the sediment, having resisted erosion, fragmentation, and reworking by processes of bioturbation (Goodman 1999). Fish bone density showed some significant chronological differences, in the same manner as the proportion of fish to other taxa (Figure 5b, Table 2). At Kala Uyuni, the Early Formative II (1.8±0.7) and Middle Formative deposits (1.8±0.7) exhibited higher fish densities than the Late Formative I (0.4±0.05). Most notably, the fish density was 3.5 times higher during the Middle Formative than during Tiwanaku IV-V times (0.5±0.1; One-way ANOVA F=7.06, $p<0.001$). Whereas, at Chiripa, comparisons show that fish density was significantly lower in the Early Formative I than during the Middle Formative (One-way ANOVA F=7.9, $p<0.001$). Results in Table 3 demonstrate that during the Late Formative II, Kala Uyuni (1.8±0.3) deposits were significantly more dense in fish than at Chiripa (0.4±0.08; one-way ANOVA F=4.9, $p<0.05$), a similar pattern as that seen in the fish proportion data. During the Middle Formative, fish density was two times lower at Chiripa than at Kala Uyuni (one-way ANOVA F=24.6, $p<0.001$). In Late Formative I times, fish remains from Kumi Kipa deposits (0.3±0.03) were less dense at either Kala Uyuni (0.4±0.05) or Sonaji (0.6±0.1; one-way ANOVA F=5.8, $p<0.01$). Finally, during Tiwanaku IV-V times, Kala Uyuni (0.5±0.8) showed a significantly higher fish density in comparison to Iwawi, located to the east of Kala Uyuni (0.2±0.04; one-way ANOVA F=5.2, $p<0.01$).

Discussion

Fish utilization in the Taraco Peninsula

Abundant fish remains from these archaeological settlements on the Taraco Peninsula provide a revealing record of the changing intensity of fishing over time. To place these results in context, we contrast the temporal trends in the relative importance fish with the sequence of environmental and socioeconomic changes in the Taraco Peninsula (Figure 5). To do this, we composed a revised version of Abbott and colleagues' (1997) sequence of lake-level changes using their episodes of lithographic erosion and sedimentation. We also removed some hypothesized periods of stability to incorporate the climatic modulations suggested by Calaway (2005). To measure demographic and socio-political change, we used regional survey data on the cumulative size of sites for each chronological period on the peninsula (Bandy 2001). Taking these three independently derived sequences together, we provide a richer understanding of human-environment interactions in the Taraco Peninsula over time.

Previous research in the region suggests that during most of the Archaic Period, the Titicaca Basin was very shallow. Mobile bands of hunter-gatherers relied on hunting wild camelids and deer, but consumed almost no fish or other aquatic resources (Aldenderfer 2009; Capriles and Albarracin-Jordan 2013). The absence of fish remains from Terminal Archaic Period sites located close to the modern shore of Lake Titicaca (Craig et al. 2010) suggests that fishing became prevalent only after rainfall and temperature conditions permitted the expansion of Lake Titicaca. As fish populations increased and the lake increased in extent, fishing would have been more predictable and productive, making fishing an economically viable and even optimal subsistence strategy.

The results of our analysis suggest that reliance on aquatic resources began on the peninsula during the period of early village formation (Early Formative times) and remained high throughout the entire period of study. Fish were taken with nets and traps and also from boats (as suggested by the representation of fish sizes consistent with species found in the open lake). Ethnographic fishing practices documented in the region indicate that fishing could have taken place at any season of the year (Levieil and Orlove 1990). In the Titicaca region, a wide range of lake-edge adaptations have emerged that included specialized fishing communities (Vellard 1951) as well as agricultural communities that complement fishing activities with pastoral tasks, craft production, and farming (La Barre 1948). This range of economic possibilities offered communities sufficient social and economic flexibility to endure in the face of lake level changes in the 19th and 20th centuries; we suggest the same was true in prehistoric times.

The skeletal completeness of typical fish remains from these sites –including hundreds of thousands of scales– indicate that the fish were cooked and served whole, probably after being boiled in ceramic pots or steamed in earth ovens. Crop agriculture and relatively specialized pastoralism were locally important throughout this time (Bruno 2008; Moore 2011). The waste from fish in middens and dumps may have provided a rich source of nutrients for fields as farming increased in productivity.

The most significant temporal variation in the use of fish is a slight decrease in relative abundance at Chiripa and Kala Uyuni, most evident between the Middle Formative and Late

Formative I times. Beginning around 250 BC, there was an almost 50% reduction in the importance of fish, a decline which continued throughout the following Late Formative period. Overall, fishing was extremely important during the early settlements and subsequent development of local agro-pastoral economies of the region, but decreased in importance as the region began to experience demographic growth and increased sociopolitical complexity in Late Formative times. Additionally, between the Middle and Late Formative the deposits became more homogeneous in density of fish bones. In other words, during the time that fish became less frequent compared to mammals and birds, that deposits with fish tended to be very dense with fish bones. The narrower range of density values is independent of sample size. Thus, by the Late Formative I, the social value of fish at public events had waned, and fishing became less important overall.

When comparing all of our data, including the lake-level estimates, the demographic changes, and the varying relative importance of aquatic resources, the changes in fish consumption on the sites does not seem to be linked to sociopolitical changes or to trade. Rather, the pattern of fish use seems to be related mainly to fluctuating ecological conditions, our first hypothesis. In addition, in the later portion of the sequence, the decline in the importance of fish might reflect a constraint on the labor available for fishing, given the increasing dependency on agriculture. As agricultural and pastoral production intensified, fishing could have taken on a different role within the local economic system. Because fish (and also birds) are wild resources, they can be a potential backup resource to buffer household subsistence in times of environmental degradation or economic uncertainty, as suggested by our fourth hypothesis. Increased fish exploitation could be seen as a strategy to manage risk associated with agricultural unpredictability in post-Formative times (see Winterhalder et al. 1999). The ownership of fishing rights and fishing equipment may also have been held according to different social rules than that for farmland and grazing land, offering another way for individual families to deal with environmental stress.

The archaeological remains show that throughout the Formative Periods fishing was a common subsistence activity for people settled by the lake. However, as agriculture, animal husbandry, and other economic activities intensified, the net contribution of fish decreased. Nevertheless, the local dietary importance of fish remained steady for those living along the shoreline. Paleoenvironmental research suggests strong climatic changes produced significant fluctuations in the lake-levels of the southern Lake Titicaca so it is significant that people in this region continued fishing, perhaps collecting fish from the remnant small lakes and seasonally available ponds, spring-fed rivers, and other similar microenvironments. Consistently high frequencies of the seeds of aquatic plants in paleoethnobotanical samples confirm that people in the Taraco Peninsula were actively using these habitats (Bruno 2008, 2011).

It is also worth considering the changing meaning of fish not only as a food staple but also as a valued commodity. A factor that could have affected the shifts observed in the archaeological record is the use of fish as a means of exchange in trade networks with sites located away from the shore, including large centers like Tiwanaku. Recent research in the Mollo Kontu residential area confirms that fish were being imported to the urban center, albeit in small amounts (Arratia 2010; Vallières 2012). In the early 20th century, fishing villages along the lakeshore have traded both fresh fish and dried fish with non-fishing communities for agricultural products (La Barre 1948; Tschopik 1946, personal observation). Evidence from Tiwanaku shows that it is unlikely that fishing was ever controlled by the increasingly centralized political organization that developed in the region, as was postulated in our third hypothesis (Capriles 2013). Under the increasing influence of Tiwanaku as an urban and political center, agricultural surplus was extracted from the southern Lake Titicaca Basin communities in increasingly centralized organizations throughout the first millennium AD. Extensive raised fields in the area northeast of the Taraco Peninsula attest to this centralized economic organization (Janusek and Kolata 2004). Nevertheless, decentralized, family organized activities such as fishing and foraging along the lakeshore continued to be an important and possibly emblematic practice engaged by rural residents outside the Tiwanaku capital on the shores of Lake Titicaca.

The question of fishing specialization in Lake Titicaca prehistory

Two models could explain the development of fishing specialization as social and economic organization around Lake Titicaca became more complex. On one hand, the emergence of communities who focused on aquatic resources could develop in association with other communities cultivating crops and keeping herds. If this were so, the fishing communities can be interpreted as occupational specialization within a diversifying economy. In this scheme, fisherfolk as a distinct social group emerged as did farming villages as a result of increased demand for staple foods in growing markets within growing towns and cities such as Tiwanaku (Gumerman 1994). Kolata (1993) and Janusek (2008) seem to support this model by speculating that the Uru fishing communities had a social identity distinct from that of Aymara agro-pastoralists and Pukina agriculturalist elites seen at the end of the Tiwanaku period (but see Wachtel 2001). In the 19th century, census records indicate that about 12% of the residents of the Taraco Peninsula were classified as Uru based on land access and economic activities (Poe 1980). These distinctions have been erased by the subsequent influence of assimilation to Aymara traditions and the effects of the agrarian reform. Further, and more likely from our archaeological data, these fishing villages may also have farmed and herded, placing them on the spectrum of farming villages rather than as exclusive fishing specialists.

Alternatively, one can view fishing as an economic strategy used by agricultural villagers. Kin groups would have held rights to fishing locations, experience, and fishing equipment, as is the situation today. Fishing could have played a significant role in buffering economic risk associated with environmental fluctuations and political instability. Fishing could also have complemented the seasonality and availability of agricultural products for local consumption. This model supports the idea that the lake fish remained a valued food, in nutrition, cuisine, and identity. Our previous subsistence-oriented studies from the Taraco Peninsula support this second model, at least up until Tiwanaku times. This model is further supported by evidence for the consumption and discard of abundant and diverse resources within the same depositional contexts, suggesting mixed ingredient food preparation and therefore procurement. Production of specialized bone tools for fish net making was found in the midst of occupational debris at Kala Uyuni, the presumed Late Formative regional center. More importantly, most subsistence resources were consumed in domestic contexts and in public spaces as part of communal ceremonies that possibly involved conspicuous consumption of food and drink (Hastorf 2003, 2008). For example, Middle Formative pits used to receive offerings of fish were identified at both Chiripa and Kala Uyuni, adjacent to ceremonial sunken courts. Culinary traditions which combined agricultural and wild foods such as fish underscore the resiliency of subsistence practices during times of environmental and social upheaval. The uniformity in the deposition and distribution of fish remains among sites, rather than a patchy distribution of sites with high proportion of fish consumption, also suggests this second model is more convincing.

The ecological history of Lake Titicaca suggests that people actively managed their environment and resources to thrive even during periods of severe climatic variation (Erickson 2006). The remains of fish and other aquatic resources from archaeological sites are not direct paleoenvironmental proxies, but they are useful indicators of how the people valued their resources and adjusted to their continuously changing environment (Bruno 2011; Moore 2011). We hypothesize that the fluctuating lake levels and the sociopolitical changes linked to the emergence of social complexity and the Tiwanaku state both were major forces affecting the use of aquatic resources in the Taraco Peninsula. However, our results document consistently high proportion and densities of fish remains throughout time with only a slight decreasing trend, thereby weakening the case for the major impact of lake level fluctuations or a political impact as causal factors in economic organization. In fact, our data suggest that fishing persisted as an important and valued social practice throughout periods of increased aridity and independently of sociopolitical integration. Nevertheless, even though finer chronological resolution for both archaeological and paleoenvironmental data is required to further assess the interplay between environment and social change, our research predicts that the nature of this relationship is bound to be complex.

Final thoughts

In this paper, we use intensive recovery techniques to quantify the economic importance of fish in southern Lake Titicaca Basin sites from the time of the emergence of early village formation up to the constitution of a state-level society. We were interested in how the interplay between the socio-political change and environmental fluctuations determined variation in resource procurement, utilization intensity, and control. The present study shows that the first sedentary inhabitants of the Taraco Peninsula relied extensively on aquatic resources but that their importance decreased only slightly when the first regional polities emerged in the region. The shift through time can best be explained by increased reliance on agricultural and pastoralist resources along with increased sociopolitical complexity.

On a methodological level, we have illustrated that changes in the consumption and discard of fish could be evaluated employing bone weight and derived measures (e.g., proportion and density) from flotation heavy fractions. The importance of microfauna, especially fish, can be understood only when using specimens collected by water flotation or other fine-mesh sieving. However, given the interdependence between quantification units and the estimated relative representation of taxa (Lyman 2008), using weight can help speed the analysis of these measures. This approach could potentially be applied at other sites in the Lake Titicaca Basin. As more flotation samples are collected for paleoethnobotanical research in this area, the potential for understanding fish exploitation in the lake will also increase. Detailed comparisons of specific cultural contexts are necessary to corroborate and clarify the trends identified in our study. Although the statistical treatments strengthen our conclusions, comparative studies from other sites are required as well. For instance, information about fish consumption at the site of

Tiwanaku itself is still very limited despite the potential importance of exchange of fresh or dried fish (Arratia 2010; Vallières 2012).

Today, Lake Titicaca’s native fish species are experiencing significant impacts from overfishing, introduction of exotic taxa, habitat degradation, and leaching of agricultural and mining chemicals and sewage waste from neighboring towns and cities (Van Damme et al. 2009). Even though past local fisheries could withstand human exploitation, environmental change and political change, the magnitude of present-day threats to Lake Titicaca are unprecedented (Sarmiento and Barrera 2004; Steffen et al. 2011). By decoding part of the long-term trajectory of human-environment interactions in the Titicaca Basin, we hope we may help foster sustainable management practices by policy makers and indigenous stakeholders (Campbell and Butler 2010).

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Figures and Tables Captions

Figure 1. Map of the Taraco Peninsula including the studied archaeological sites and Lake Titicaca's bathymetry.

Figure 2. Tiwanaku's iconographic representation of fishes in the Gateway of the Sun (a-b modified from Posnansky 1945:Plates 42-43) compared to drawings of c) *Trichomycterus* and d) *Orestias* (not to scale).

Figure 3. Relationship between a) NISP and weight and b) MNI and weight for fish remains recovered and identified from flotation remains from the site of Kala Uyuni (N=31). Lines show best fit (a, $r^2=0.944$; b, $r^2=0.89$) for log10-transformed data.

Figure 4. Relationship between fish bone proportion and density for all the studied flotation samples (N=367). Line shows linear best fit ($r^2=0.173$) for log10-transformed data.

Figure 5. Box-plots showing the changes by period and site on a) fish proportions and b) density throughout time.

Figure 6. Composite graph showing the temporal sequence of fish utilization as box-plots showing the grouped results from all studied sites for each phase, Lake Titicaca level changes (redrawn with modifications from Abbott et al. 1997:Fig. 2), and accumulated settlement surface area from the Taraco Peninsula (based on Bandy 2001:Appendix A).

Table 1. Description of excavated sites and the flotation samples used in this study sorted by site and chronological period.

Table 2. Temporal comparisons of fish bone weight and density across archaeological sites using one-way ANOVAs. Significant Tukey post-hoc tests are flagged in bold and identified using superscripted lower-case letters.

Table 3. Spatial comparisons of fish bone weight and density across periods using one-way ANOVAs. Significant Tukey post-hoc tests are flagged in bold and identified using superscripted lower-case letters.

Table

Table 1. Description of excavated sites and the flotation samples used in this study sorted by site and chronological period.

Site	Description	Period						Total
		EF I	EF II	MF	LF I	LF II	Tiw	
Kala Uyuni	The site is a multi-component occupation that increased in size, complexity, and regional importance through time. Two sunken courts were built in the highest sector of the site during the MF and an architectural complex was built during the LF I in the lower sector, when the site emerged as the peninsula's regional center.	4	6	32	45	6	13	106
Chiripa	Chiripa has a complex sequence of occupation that includes evidence for various sunken courts built during the EFII followed by different cycles of renewal. Excavations in several sectors across the site exposed the presence of various sunken courts and associated domestic and ritual activities.	46	26	109				181
Sonaji	Excavations at the site documented multiple trash midden levels intersected by deep refuse pits on a single large and deep block. Architecture is evident for initial level of occupation but the later components of the sequence mainly consist of refuse of activities carried out elsewhere.				18	3	5	26
Kumi Kipa	This a large located on the western edge of the peninsula. Excavations here revealed the existence of a complex of structures associated with the Late Formative I as well as later occupations including the building of a burial mound during Tiwanaku IV-V.				30			30
Iwawi	The site includes a large mound composed of multiple and successive occupations, several burials, and even some monumental architecture. Iwawi probably served as a regional population, administrative center, and lake port during Tiwanaku IV-V.						24	24
Total		50	32	141	93	9	42	367

Table 2. Temporal comparisons of fish frequency and fish density across archaeological sites using one-way ANOVAs. Significant Tukey post-hoc tests are flagged in bold and identified using superscripted lower-case letters.

Site		Period						F	*P*
		EF I	EF II	MF	LF I	LF II	Tiw		
Kala Uyuni	Fish proportion	59.7±13^{ab}	38.9±5^{ab}	**56.1±4^{a}**	**24±3^{b}**	25.1±9^{ab}	**19.6±3^{b}**	7	<0.001
	Fish density	1.2±0.3^{abc}	**1.8±0.7^{ac}**	**1.8±0.3^{a}**	**0.4±0.05^{bc}**	0.4±0.2^{abc}	**0.5±0.1^{bc}**	7.1	<0.001
Chiripa	Fish proportion	**37.9±3^{a}**	**23.8±4^{b}**	**38.9±2^{a}**				8.4	<0.001
	Fish density	**0.7±0.1^{a}**	0.4±0.2^{ab}	**0.9±0.1^{b}**				7.9	<0.001
Sonaji	Fish proportion				35.3±5	26.3±9	22.9±6	0.8	0.4
	Fish density				0.59±0.1	0.72±0.1	0.6±0.1	0.5	0.6
All sites	Fish proportion	**39.7±3^{a}**	**26.6±3.4^{b}**	**42.8±2.1^{a}**	**25.2±1.9^{b}**	25.5±6.3^{ab}	**22.9±2.3^{b}**	7.7	<0.001
	Fish density	**0.7±0.1^{a}**	0.7±0.2^{ab}	**1.1±0.3^{b}**	0.4±0.03^{ab}	0.5±0.1^{ab}	**0.3±0.04^{b}**	2.94	<0.05

Table 3. Spatial comparisons of fish frequency and fish density across periods using one-way ANOVAs. Significant Tukey post-hoc tests are flagged in bold and identified using superscripted lower-case letters.

Period		Site					F	*P*
		Kala Uyuni	Chiripa	Sonaji	Kumi Kipa	Iwawi		
Early Formative I	Fish proportion	59.7±6	37.9±3				2.2	0.1
	Fish density	1.2±0.3	0.7±0.1				2.7	0.1
Early Formative II	Fish proportion	38.9±6	23.8±3.8				3	0.09
	Fish density	**1.8±0.7^{a}**	**0.4±0.1^{b}**				4.9	<0.05
Middle Formative	Fish proportion	**56.1±4.3^{a}**	**38.9±2.4^{b}**				7.2	<0.001
	Fish density	**1.8±0.3^{a}**	**0.9±0.4^{b}**				24.6	<0.001
Late Formative I	Fish proportion	24.1±3^{ab}		**35.3±5^{a}**	**20.7±3^{b}**		2.9	0.059
	Fish density	**0.4±0.1^{a}**		**0.6±0.1^{a}**	**0.3±0.03^{b}**		5.8	<0.001
Late Formative II	Fish proportion	25.1±9		26.3±9			0.16	0.7
	Fish density	0.4±0.2		0.7±0.1			2.6	0.1
Tiwanaku IV-V	Fish proportion	19.6±3.4		22.9±7		24.8±3.4	0.02	0.9
	Fish density	**0.5±0.1^{a}**		0.6±0.2^{ab}		**0.2±0.04^{b}**	5.2	<0.01

Figure 1

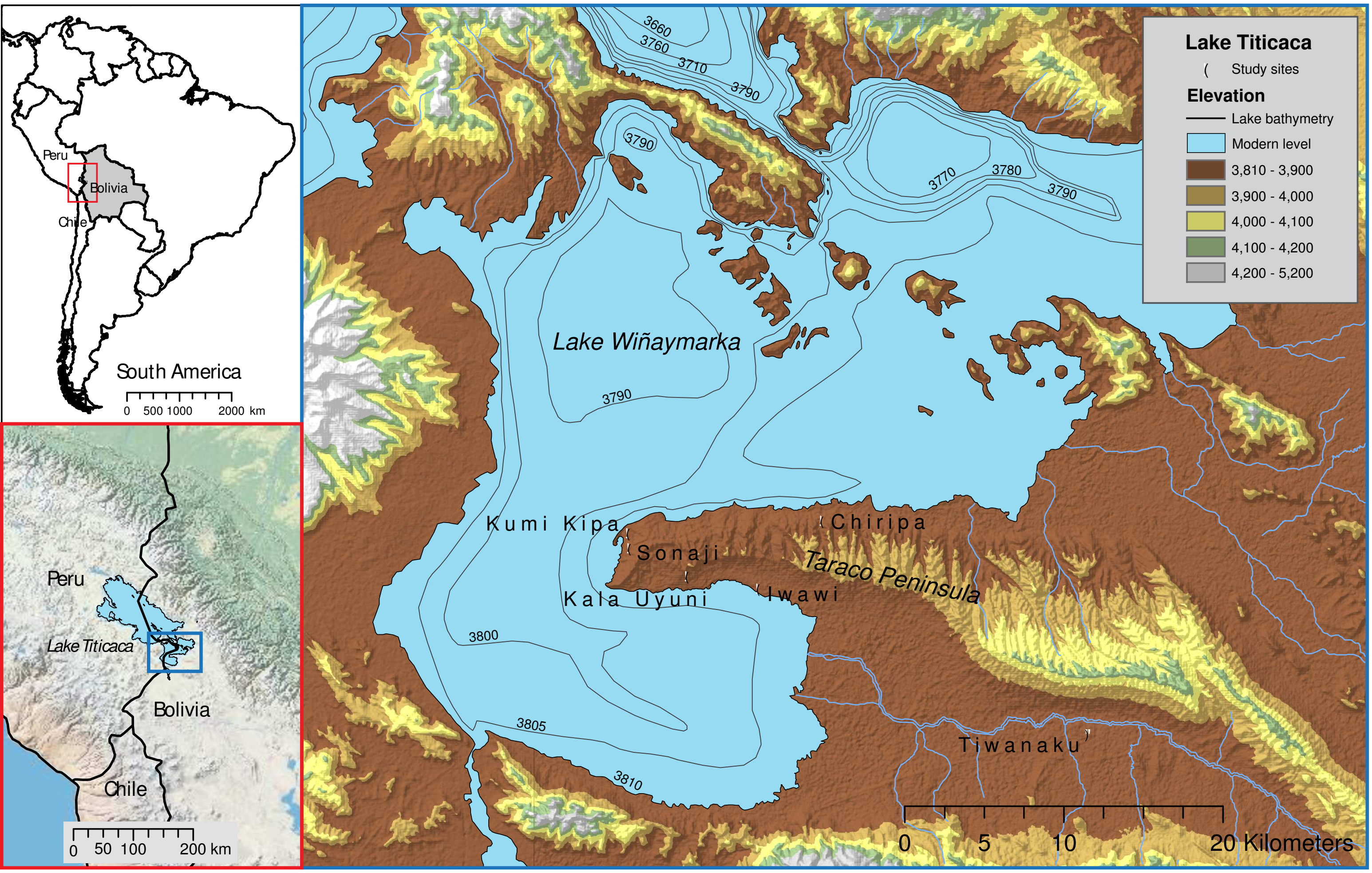

Peru
Bolivia
Chile
South America
0 500 1000 2000 km
Peru
Lake Titicaca
Bolivia
Chile
0 50 100 200 km
Lake Titicaca
Study sites
Elevation
Lake bathymetry
Modern level
3,810 - 3,900
3,900 - 4,000
4,000 - 4,100
4,100 - 4,200
4,200 - 5,200
3660
3760
3710
3790
3790
3770
3780
3790
Lake Wiñaymarka
3790
Kumi Kipa
Sonaji
Chiripa
Taraco Peninsula
Kala Uyuni
Iwawi
3800
3805
3810
Tiwanaku
0 5 10 20 Kilometers

Figure 2

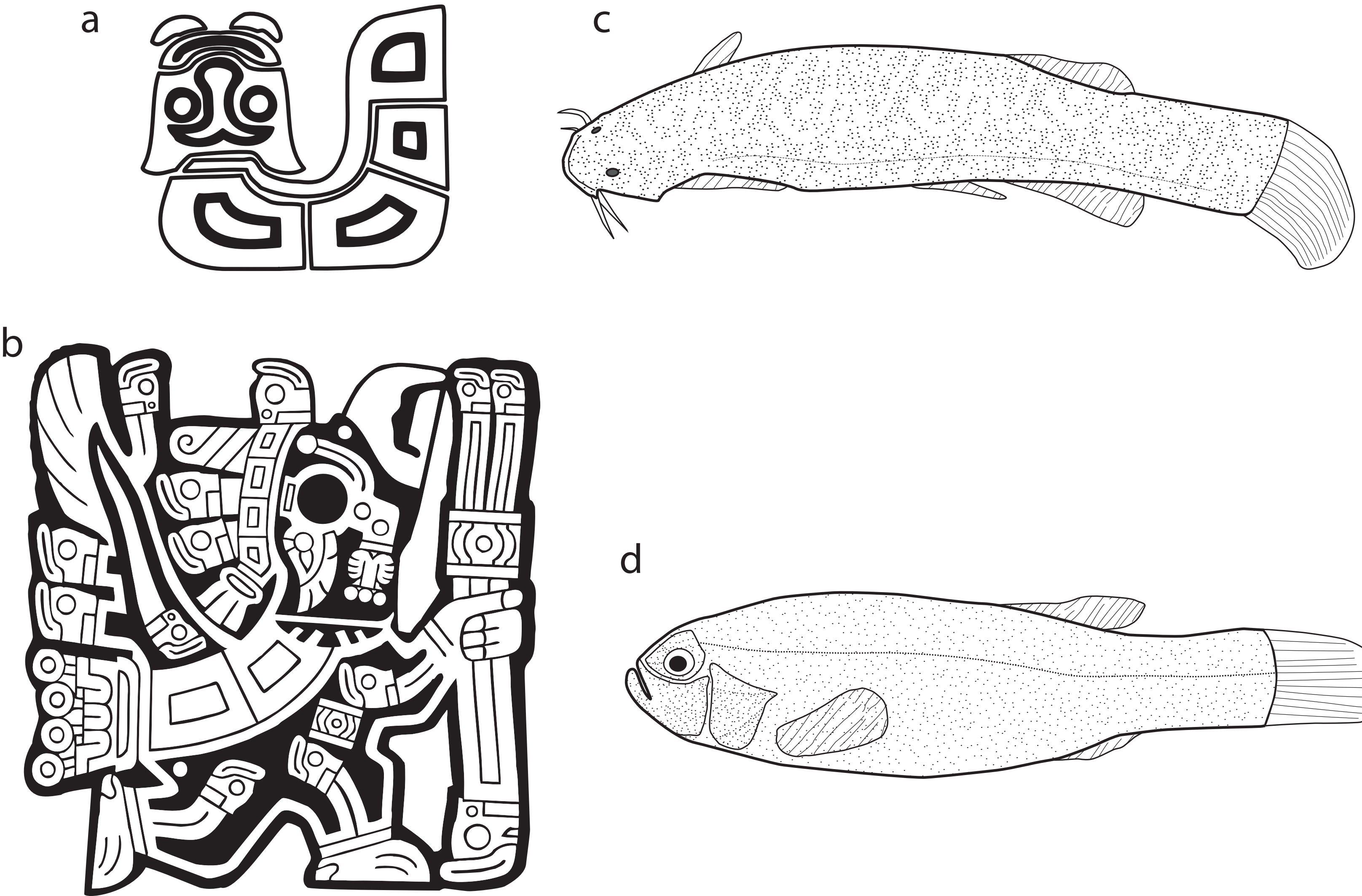


Figure 3

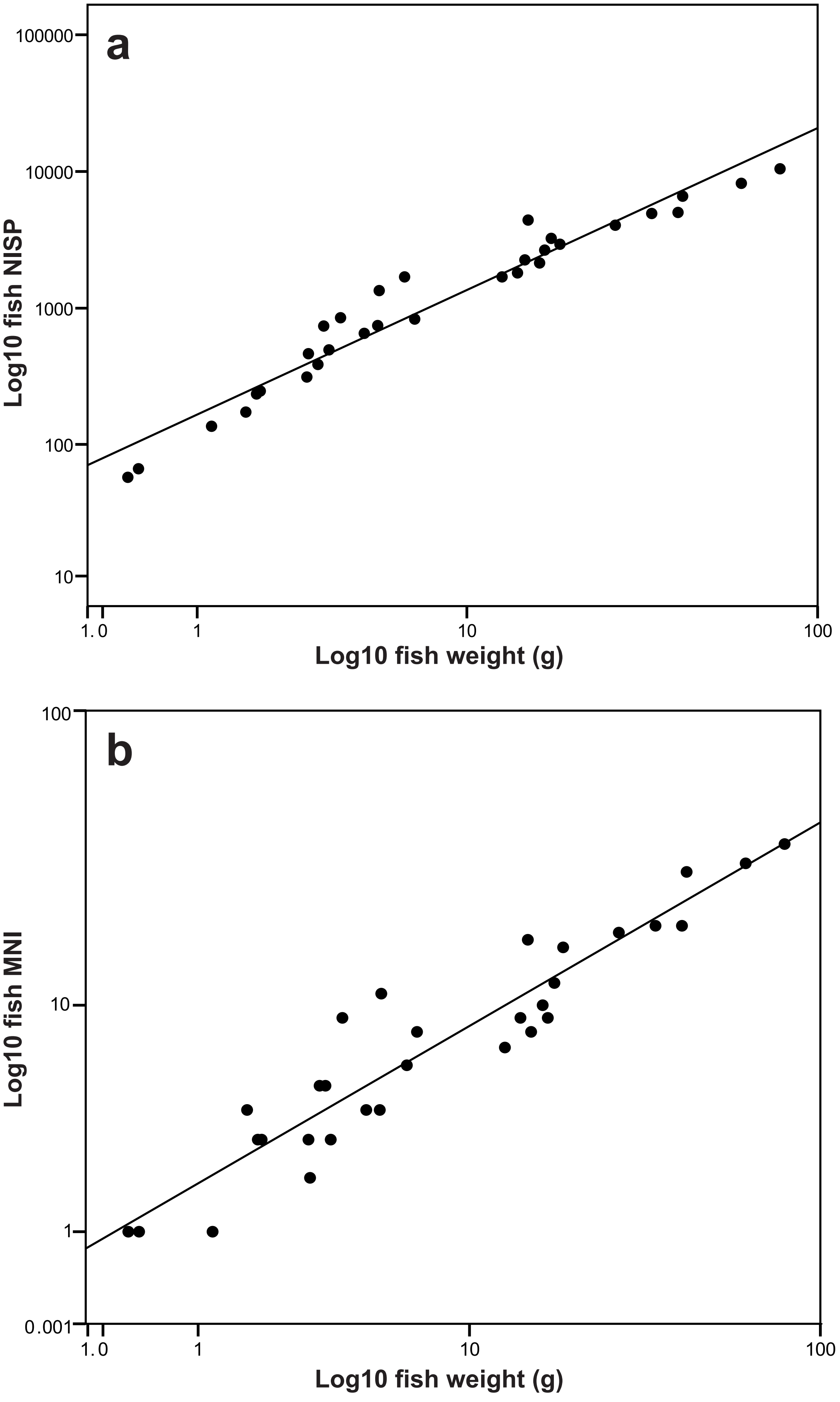
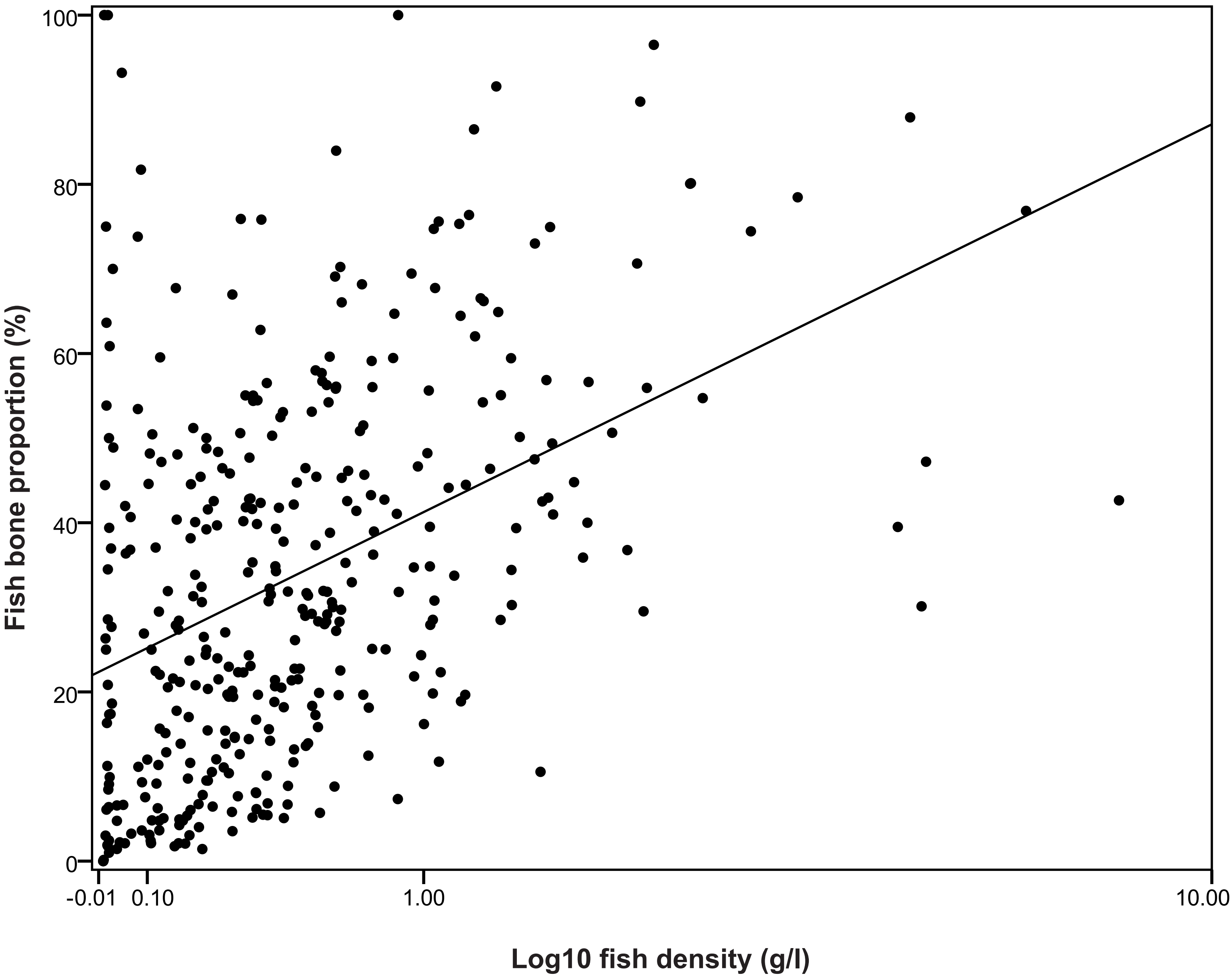

a
100000
10000
1000
100
10
Log10 fish NISP
1.0
1
10
100
Log10 fish weight (g)
b
100
10
1
0.001
Log10 fish MNI
1.0
1
10
100
Log10 fish weight (g)

Figure 4



Fish bone proportion (%)
100
80
60
40
20
0
-0.01
0.10
1.00
10.00
Log10 fish density (g/l)

Figure 5

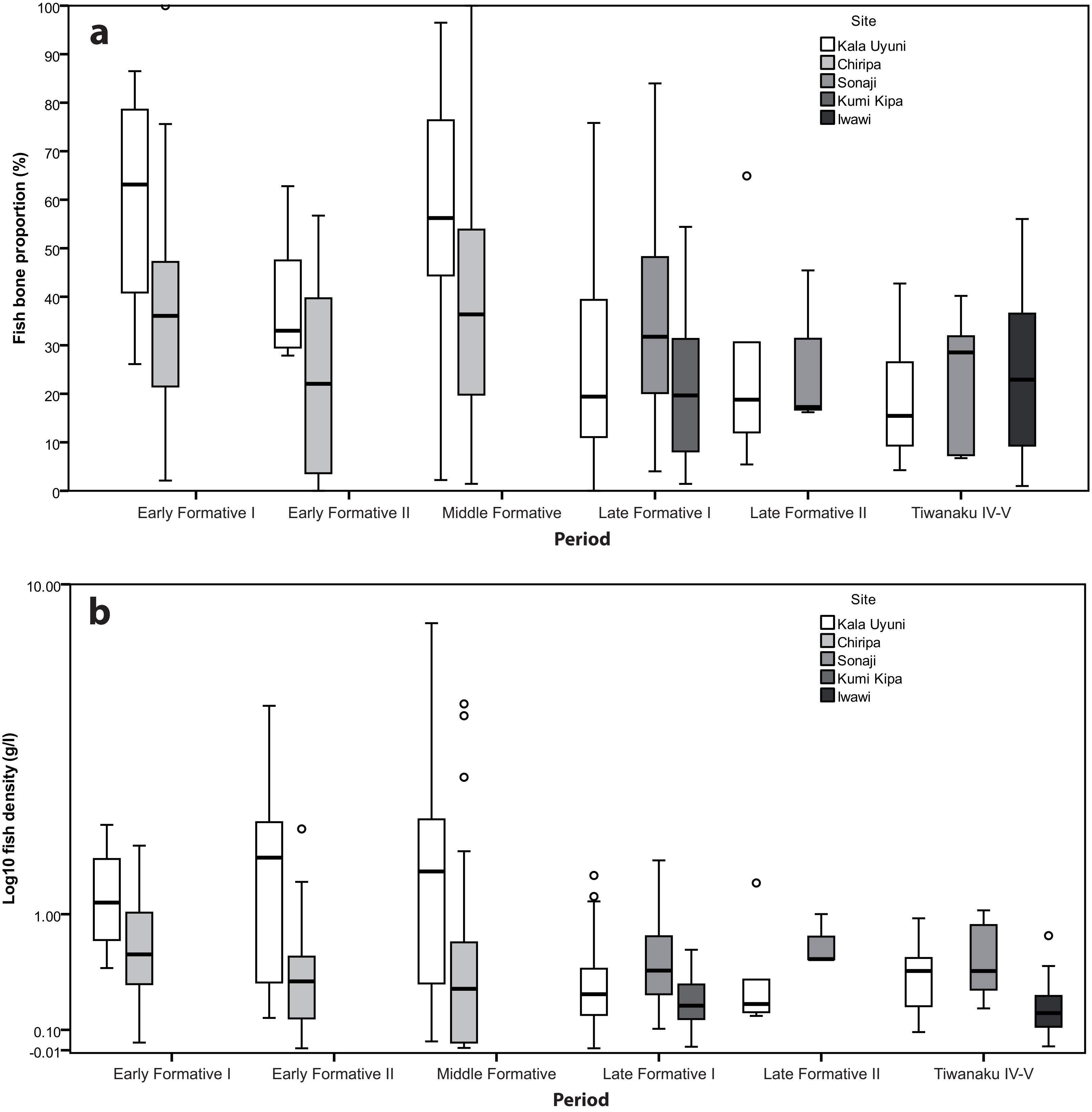
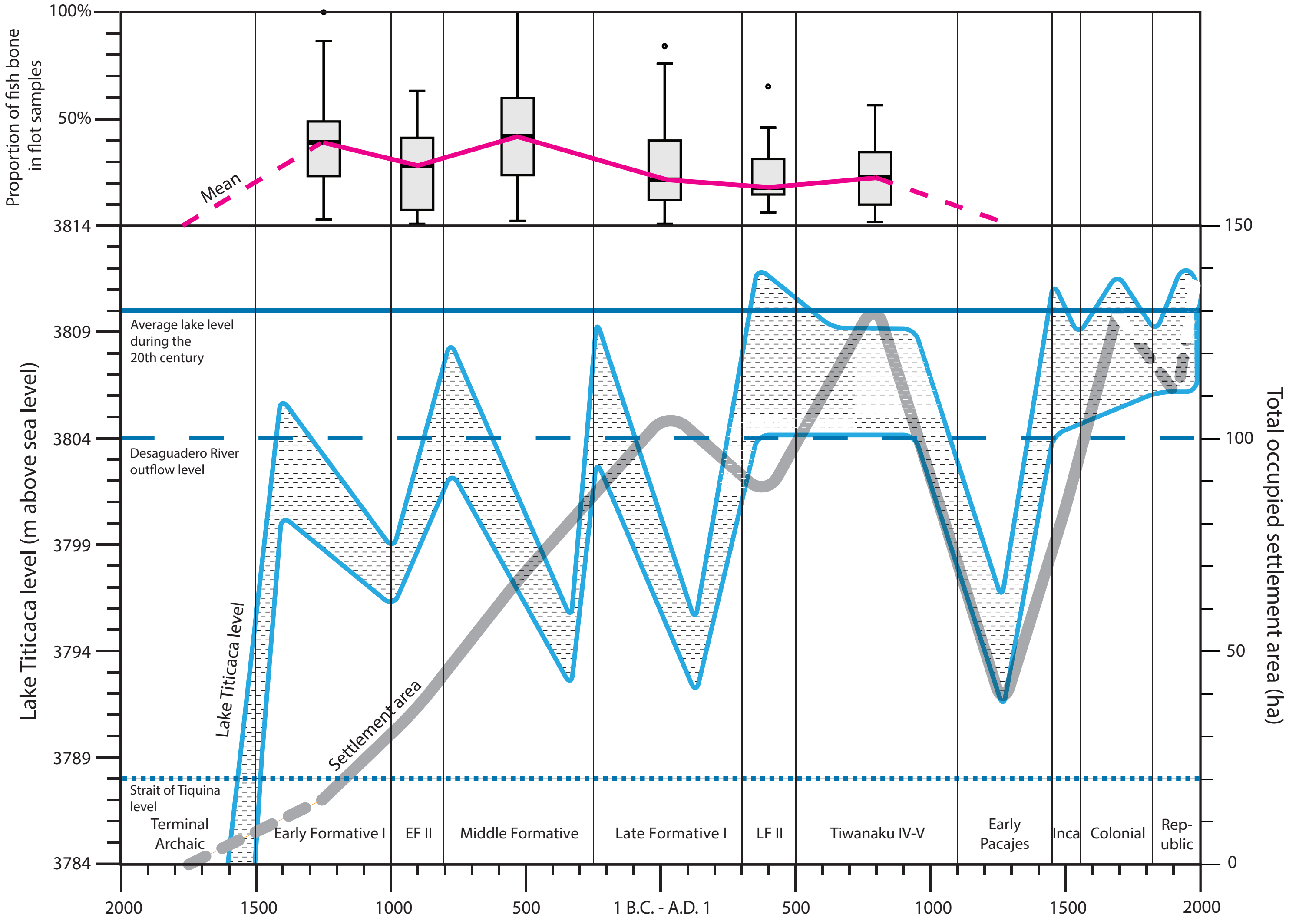

a
Fish bone proportion (%)
0
10
20
30
40
50
60
70
80
90
100
Site
Kala Uyuni
Chiripa
Sonaji
Kumi Kipa
Iwawi
Early Formative I
Early Formative II
Middle Formative
Late Formative I
Late Formative II
Tiwanaku IV-V
Period
b
Log10 fish density (g/l)
10.00
1.00
0.10
-0.01
Site
Kala Uyuni
Chiripa
Sonaji
Kumi Kipa
Iwawi
Early Formative I
Early Formative II
Middle Formative
Late Formative I
Late Formative II
Tiwanaku IV-V
Period

Figure 6



100%
50%
3814
Proportion of fish bone in flot samples
Mean
3809
3804
3799
3794
3789
3784
Lake Titicaca level (m above sea level)
Average lake level during the 20th century
Desaguadero River outflow level
Strait of Tiquina level
Lake Titicaca level
Settlement area
150
100
50
0
Total occupied settlement area (ha)
Terminal Archaic
Early Formative I
EF II
Middle Formative
Late Formative I
LF II
Tiwanaku IV-V
Early Pacajes
Inca
Colonial
Rep-ublic
2000
1500
1000
500
1 B.C. - A.D. 1
500
1000
1500
2000