

An Investigation into the Decline of the Tiwanaku Polity: Exploring the Role of Salinization

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ABSTRACT

The decline and collapse of the Tiwanaku state, based in the Lake Titicaca Basin of Bolivia, occurred during what scholars call the Tiwanaku V Phase (A.D. 800-1200), a period of great environmental stress induced by prolonged droughts and various other natural hazards. It was during this period that raised field (*waru waru*) agriculture—long considered the linchpin that held together the Tiwanaku polity—gradually fell into widespread disuse and considerable changes occurred with regards to the overall health, demographics, and subsistence strategies of the Tiwanaku people. As of late, the dependence of Tiwanaku peoples on raised field systems as well as the fundamental productivity of those systems has come under scrutiny. Matthew Bandy speculates that raised field systems were never overly productive and that dense potato cyst nematode populations may have decimated the subsistence systems of ancient indigenous farmers. The current research elaborates upon Bandy's innovative and compelling theory. This paper presents evidence that salinization, brought about by both natural and anthropogenic factors, aided in the proliferation of nematode populations and served as a joint impetus for the abandonment of raised field systems.

INTRODUCTION

The Andean landscape is remarkable for its juxtaposition of contrasts—ranging from desert to jungle and from sea-level to snowy peaks over 23,000 feet (7,000 meters) high. The indigenous peoples of this region have always developed complex and sophisticated ways to meet its challenges, building irrigation networks to make the desert more fertile and terracing steep highland slopes to create more arable land (Von Hagen and Morris 1998:13). Exemplified by the Paracas, the Nazca, and the Moche of antiquity and the Aymara and Quechua peoples of the present, the evolution of human culture in the Andes has been strongly dictated by the natural environment, a context in which some societies rose to prominence and eventually collapsed. As I hope to illustrate in this paper, the destinies of at least two prehistoric Andean societies—cultures of profound sophistication and influence—were altered by changes to their ecological surroundings. All too often, environmental degradation, the disruption of a delicate equilibrium caused either by natural or anthropogenic processes, has served as the stimulus for cultural decline and collapse in this region.

Figure 1. Map of Peru and Bolivia in relation to the South American continent.



Figure 2. Enlarged map of the Lake Titicaca Basin and associated cities.



Andean prehistory is a brilliant mosaic of cultural florescence, witnessing the emergence of highly developed and well-documented societies like the Chimu and the Inca. The Inca, known for possessing a polity that rivaled the Roman Empire in size, was not the first true “empire” of the Andes. That distinction could, some argue, be given to the Tiwanaku, an extraordinarily complex and mysterious polity that emerged in the Lake Titicaca Basin centuries before the Inca. Their capital city of Tiwanaku, situated on the southern shores of Lake Titicaca in the modern nation of Bolivia (see Figures 1 and 2 above), was constructed on a monumental scale yet remains enigmatic. The 19th century traveler and explorer, E. George Squier, gazing upon the ruins of the city nearly a century and a half ago, remarked the following:

The first thing that strikes the visitor in the village of Tiahuanaco (Tiwanaku) is the great number of beautifully cut stones, built into the rudest edifices, and paving the squalidest courts. They are used in lintels, jambs, seats, tables, and as receptacles for water. The church is mainly built of them; the cross in front of it stands on a stone pedestal which shames the symbols it supports in excellence of workmanship (Von Hagen and Morris 1998:118).

The city was founded circa A.D. 200 and maintained for nearly a millennium, finally abandoned around A.D. 1100-1200. At its zenith, the site may have accommodated between 20,000 and 40,000 inhabitants, although the city’s population grew when it took in pilgrims or the masons and stone-carvers occupied in constructing its monuments (Von Hagen and Morris 1998:119,126). These figures, however, represent a mere fraction of the population associated with the ancient city (Kolata 2003a:50). The sheer size and grandeur of both its capital and various other sites attributed to its domain indicates that the Tiwanaku polity was typical of many other state-level societies in prehistory: rigidly hierarchical in nature, supported by a large population of artisans, farmers, and elite patrons, and constantly involved in trade, colonization, and possibly even military expansion as a means of fueling growth and development (Von Hagen and Morris 1998:125,127). Although ancient Tiwanaku society may superficially possess a number of the same universal attributes as other prehistoric state-level societies, a number of tantalizing questions still linger, questions that emphasize the sheer uniqueness of this wondrous civilization. For example, what factors lead to the emergence of the polity and allowed it to prosper for a millennium in such a challenging landscape? Also, what fueled its expansion and how were resources acquired; through militarism, trade, religious affiliation, or perhaps a combination? Lastly, what factors lead to its decline and eventual collapse?

Many of the aforementioned questions have been addressed and clarified by Andean archaeologists in the years since Squier first paid homage to the Tiwanaku, however, many more questions have arisen to take their place. The goal of this paper is to evaluate whether or not salinization played a factor in the abandonment of raised field (*waru waru*) agriculture, long considered the linchpin of the Tiwanaku polity.

METHODOLOGY

In order to gain a better understanding of the topic of raised field agriculture as a whole, I first reviewed research by Alan Kolata (1986, 1991, 1993, 2003a, 2003b), Clark Erickson (1993, 2000), and Arthur Morris (1999). These works have provided invaluable information regarding the supposed strengths of raised field agriculture, the extent to which it was employed by indigenous peoples in the Lake Titicaca Basin during each cultural phase of Tiwanaku occupation, and the niche this type of agriculture would have found in the lives of various groups in the region. More specifically, the work of Alan Kolata (2003a, 2003b) outlined in great detail some of the latest archaeological work conducted in the basin. It is from this source that much of the information presented in this paper regarding archaeological correlates of salinization was obtained.

Research into raised field agriculture in the Lake Titicaca Basin inevitably led to a number of studies documenting periods of prolonged drought in the region. Two limnological studies (Binford et al. 1997, Abbott et al. 1997) used sediment cores to obtain information regarding fluctuations of Lake Titicaca’s water level through time, fluctuations that had a profound impact on the amount of cultivable land in the basin. Another study (Fritz et al. 2003) documented the extreme antiquity of these devastating droughts, lending credence to the instability of Andean environments during even the earliest periods of human occupation in the region. An earlier study (Shimada et al. 1991) utilized ice core samples from the Quelccaya ice cap in southern Peru to document fluctuations in the precipitation levels during certain stages of Moche culture, a polity whose own lifespan overlapped much of the Tiwanaku’s. This study, in conjunction with archaeological evidence from a number of ancient settlements, highlights the debilitating effects prolonged droughts can have on highly-advanced agriculturally-dependent societies like the Moche and Tiwanaku.

Changing settlement patterns in the basin during different cultural periods have been documented by a number of Andean scholars. The most helpful studies included Kolata (2003b), Albarracin-Jordan and Matthews (1990), as well as McAndrews et al. (1997). These studies allowed me to correlate changing climatic conditions with marked population shifts evident in the archaeological record.

An interest in the process of salinization led me to the work of W.D. Williams (1999) and Edward Goldsmith (1984). Their research elucidated the various stages of salinization, the various contributing causes of the process, and the potential effects this destructive process can have on agricultural practices in diverse ecological settings.

Certain research interests next led me to the work of Matthew Bandy. It was his article (Bandy 2005) that emphasized the fragility of raised field systems in the Lake Titicaca Basin, contradicting the long-held notion of raised field invincibility. His theory regarding the infestation of native cultigens by parasitic potato cyst nematodes led me to consider the idea that perhaps other undocumented factors could have contributed to the decline of *waru waru* agriculture in the region. The underlying causes behind the proliferation of nematode populations in Andean soils, largely unaddressed by Bandy, compelled me to research the nematode, its ability to develop in certain soils, its overall infectivity of certain cultigens, as well as methods employed by modern farmers to control runaway nematode populations.

A need for more specific information pertaining to potato cyst nematodes led me to the works of Dufour et al. (1998), Spears (1968), and Hockland (2002). These studies have yielded both general information regarding nematode characteristics, general habitat preferences, and biological controls, as well as more detailed information regarding documented infestations of *Globodera rostochiensis* and *Globodera pallida*, outlining both signs of infestation and the resultant effects on crop yields.

In order to establish a case for salinization in the basin, data was needed regarding the natural environment of the region. Information outlining the geographic and meteorological characteristics of the Lake Titicaca Basin was obtained from case studies by the Binational Autonomous Authority of Lake Titicaca (1992, 2003); these studies were invaluable in establishing correlations between the ecological settings of the basin and settings in which salinization has been most prevalent.

During the course of my research, the archaeological ubiquity of quinoa, outlined in Kolata (2003a), drew my attention to native cultigens of the region. Data regarding the halotolerance of cultigens like quinoa and barley was obtained from Shannon (1997), Dickson (1987), and Jacobsen et al. (2000). These studies contributed greatly towards establishing a case for salinization in the basin, correlating almost perfectly with floral evidence recovered by Andean scholars.

WHAT IS SALINIZATION?

All soils contain salt. That salt is the result of what geologists call “weathering,” the natural chemical, biological and physical processes which lead to the gradual breakdown of rocks and other geological formations. As those rocks are worn down, they release their natural salts into the soil, generally to be dissolved in rainwater (Goldsmith 1984:1). In addition, all water contains salt. Although oceanic evaporation produces water essentially free of electrolytes, all precipitation contains small but significant amounts of dissolved salts (Williams 2001:86). Even a fresh mountain stream will contain up to 50 parts per million (ppm) of salt—admittedly a minute amount compared to the 35,000 ppm content of seawater, but significant nonetheless (Goldsmith 1984:1).

Semi-arid and arid regions (drylands with an annual mean rainfall between 25 and 500 mm) cover approximately one-third of the world’s land area and are inhabited by almost 400 million people. Because they are a resource in short supply, waters in drylands are under increasing human pressures, and many are threatened by rising salinities (salinization) in particular (Williams 1999:85). The salinities of many large natural salt lakes in drylands are rising as water is diverted from their inflows for irrigation and other uses. The excessive clearance of natural, deep-rooted vegetation from catchments and the discharge of saline agricultural wastewater cause the salinity of many freshwater lakes, wetlands, and river to rise. Increasing climatic aridity may also be a cause of salinization (Williams 1999:85).

Salinization is a process that increases the salinity of inland waters (salt lakes, freshwater lakes and streams, etc.), occurring either by natural processes (primary salinization) or by anthropogenic processes (secondary salinization). Natural or primary salinization is mainly restricted to closed (endorheic) drainage basins in semi-arid or arid regions of the planet. Not without coincidence, these regions are also where secondary salinization is most prevalent (Williams 1999:85). In exorheically drained (open) basins, the salt is more or less directly returned to the ocean, but in endorheically drained basins, it accumulates in terminal basins where, following solar evaporation, it gives rise to saline lakes. The evaporation rates in hot arid and semi-arid lands are anywhere between four to five times higher than those in temperate areas (Goldsmith 1984:1). This process is known as natural salinization

(Williams 1999:86) and has caused almost 45% of global epicontinental waters to become more salinized (Williams 2001:87).

Due to human activities and disturbances, the already elevated saline levels of many salt lakes are on the rise, inciting further ecological stress. Some famous salt lakes around the world include the Great Salt Lake in Utah, Mono Lake in California, Lake Corangamite in Australia, Pyramid Lake in Nevada, and the Dead Sea in the Middle East. W.D. Williams, an Australian biologist and expert on salinization, provides a striking example of the reciprocal nature of salinization; destructive human activities can elevate the saline levels of water bodies like salt lakes while elevated salinities, in turn, can adversely affect the natural biota living in those water bodies as well as neighboring human populations. In the Aral Sea, another famous salt lake, rising salinities were accompanied by falling water levels (>15m between 1960 and 1991), a decreased water surface area, the exposure of extensive tracts of lake bed, hotter summers, and marked changes in both the biota and biological condition of the lake. Increased salinity led to the demise of the economically and socially important fishery of the lake. An increase in the frequency of dust storms and a decrease in agricultural productivity surrounding the lake (likely due to salt deposition) also developed (Williams 1999:87). These increases in dust storms also led to an increase in the frequency of both respiratory illnesses and other human ailments (Williams 1999:87).

The process of salinization is especially problematic in freshwater lakes and streams due to the fact that freshwater ecosystems are considerably more sensitive to salinity increases than salt lakes, and even small rises have profound effects. The most important human activities in the process of salinization in these water bodies are the clearance of natural vegetation (deforestation) and irrigation. In south-western Australia, many formerly freshwater lakes and wetlands have become salinized after their catchments were cleared of deep-rooted vegetation with high transpiration rates (mostly trees), and replaced with shallow-rooted crops with lower rates of transpiration. Both events can mobilize subsurface salt and the mobilized salt, in turn, can salinize freshwater lakes and wetlands within the catchment (Williams 2001:89). The greatest impact occurs when the original salinities of water bodies are low due to the high sensitivity of freshwater bodies, as stated earlier. Salinization also degrades the quality of shallow groundwater and surface waters such as ponds, sloughs, and dugouts. Evaporation may concentrate salt in these waters to levels that pose a risk to the health of livestock and wildlife. It should be noted that highly salinized waters are also quite hazardous to freshwater fish populations—exemplified in the aforementioned Aral Sea case study—and are generally avoided by waterfowl (Eilers 1995:4).

The core reason for the rises in salinity in almost all cases is the diversion of inflowing river waters for agriculture (i.e., irrigation) and other uses. The FAO estimates that at least 50% of the world's irrigated land now suffers from salinization although Victor Kovda argues that that percentage may be closer to 60-80% (Goldsmith 1984:3). With decreased inflows, the hydrological balance changes and lake volume decreases with consequent rises in salinity, since the salt mass of a hydrological system remains more or less constant (William 1999:86). In almost all the arid areas of the world where irrigation is practiced—the valleys of the Tigris and Euphrates, the Helmand Valley of Afghanistan, or the Imperial and San Joaquin Valleys of California—the sub-soil is relatively impermeable, making down-drainage deficient (Goldsmith 1984:5). Not only does irrigation increase the extent of vegetation cover—and hence the rates of transpiration—it also requires water to be spread thinly over a wide area, thus raising direct evaporation losses. The inevitable result of high evapo-transpiration is that the natural salt in water becomes concentrated in the soil (Goldsmith 1984:2). One way of slowing the salting of soils is to irrigate at night so as to significantly reduce the role of evaporation.

Where the water table is lowered too far (as has happened in certain parts of the southwestern United States), there is a tendency for aquifers to become so depleted that they are cut off from both their points of inflow and their points of outflow. In such circumstances, the aquifers become closed basins in which used irrigation water accumulates (Goldsmith 1984:6). The over-use of irrigation water (a practice common to irrigation schemes the world over) helps to raise the water table and hence further increases waterlogging (Goldsmith 1984:2). If the water table is permitted to rise to within 2.5 meters of the surface, then the groundwaters are drawn upwards through capillary action, adding still further to their own salt burden on the way but dissolving the salts in the soils near the surface. In effect, the land becomes waterlogged with increasingly saline water (Goldsmith 1984:1). In the Shaanxi Province of China, the waterlogging of wheat and cotton has been carefully recorded, and it was found that normal yields could be sustained so long as the water table remained 2 to 3 meters below the surface. When it rose to within 1 meter of the surface and hence the root zone, wheat yields fell to 20% of the norm and cotton yields to 50% of the norm. When the water table rose to .5 meters and higher, wheat production fell to zero and cotton production fell to between 20% and 5% of the norm (Goldsmith 1984:1).

The identification and control of salinized soils is absolutely crucial if farmers ever hope to recover the lost fertility of their lands. It may be possible to identify saline soils before they are seriously afflicted. The early signs of soil salinity include (i) a surge in crop growth, producing high yields; (ii) increased soil wetness, to the point that

the area becomes inaccessible; and (iii) the growth of salt-tolerant weeds among the crop. As salt levels in the soil increase, the signs become more obvious. They include (i) irregular crop growth patterns and a lack of plant vigor; (ii) white surface-crusting; (iii) white spots and streaks in the soil, even where no surface crusting shows; and (iv) the presence of naturally growing, salt-tolerant vegetation. Conservation farming practices that help to control soil salinity include reducing summerfallow, extending crop rotations, using conservation tillage, adding organic matter to the soil, and planting salt-tolerant crops (Eilers 1995:1). In the modern world, one scheme for the prevention of soil salinization is the lining of irrigation canals, thereby reducing seepage. Unfortunately, the cost of lining canals is exorbitant, one reason why lining is rarely installed unless absolutely necessary (Eilers 1995:8).

W.D. Williams states that “salinization is an actual or potential environmental threat for a quarter of the world’s total land area and water-bodies within that area” (Williams 2001:88). In addition, he adds that the impacts of secondary salinization are “always adverse, manifold, and for practical purposes, irreversible” (Williams 1999:85). When one considers the enormity of these statements, the destructive threat of salinization—devoid of any real press coverage and routinely marginalized by even some of the world’s most noted experts—becomes a very real and all too conceivable threat. Moderate to severe salinity, persisting more or less visibly in the landscape, can reduce the annual yields of most cereal and oilseed crops by about 50% (Eilers 1995:2). My point to this blitzkrieg of statistics and citations is that not only does salinization occur, it occurs in a frightening percentage of the earth’s arable lands and human populations have paid and will continue to pay a hefty price (in their yields, their health, etc.) once it takes root.

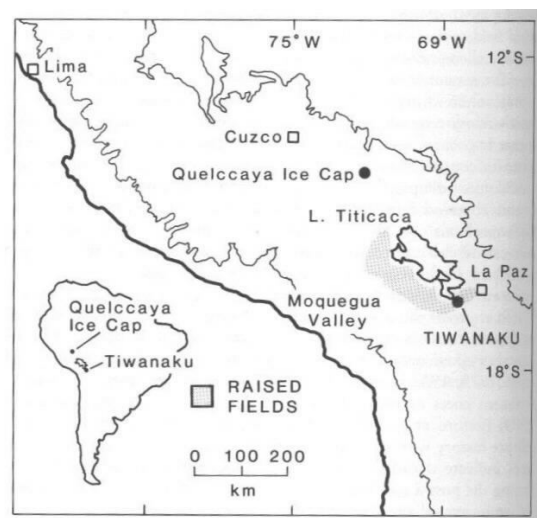
DROUGHT IN THE ANDES

Evidence from Ice Cores

The Quelccaya Ice Cap is situated on the eastern cordillera of the Andes, firmly in the tropics, north of the subtropical Altiplano, and it experiences precipitation amounts similar to the rest of Peru (see Figure 3). A number of scholars have proposed that ice core samples be extracted from this frozen formation so as to serve as indicators of precipitation patterns in the Andes, especially in Peru, during the last 1,500 years or so (Shimada et al. 1991; Thompson et al. 1984, 1985, 1991, 1994; Thompson and Moseley-Thompson 1987; Brecher et al. 1993). Severe droughts or dramatic El Niño events, many have posited, should be evident in the ice cores. One such study, Shimada et al. 1991, attempted to correlate evidence of extreme El Niño events hidden in the ice of the Quelccaya Glacier with archaeological evidence in Peru relating to the collapse of Moche civilization.

Figure 3. Map of the Quelccaya Ice Cap and its relative position to the city of Tiwanaku.

Map taken directly from Kolata 1993:286



Known for their exquisite painted ceramics and imposing adobe pyramids, the Moche people established an enormous polity in a rather inhospitable and tenuous environment. Shimada and his team focused on a 150-year period between A.D. 500 and 650, a time when the Moche and other contemporaneous cultures in Peru underwent rapid and far-reaching internal transformations (Shimada et al. 1991:248). Before this particular study, scholars had asserted that unstable climatic patterns may have contributed to the decline of this unique civilization, however, the use of ice core samples gave archaeologists an unprecedented look at just how severe or encompassing those patterns may have been.

The meteorological data extracted from the ice cores showed that during the century-and-a-half long window of study, extreme El Niño events brought torrential rains and flash flooding to the western slopes of the Andes. Severe El Niños have also been tied to intense but short-term droughts in the southern highlands and *Altiplano* and because of this, short-term, abrupt drought signatures may indicate certain intense El Niño events (Shimada 1991:258). Visible dust layers reflect the annual wet season/dry season cycle and make it possible to integrate and refine the dating of records. A three-decade long drought occurred abruptly between A.D. 563 and 594, exhibiting a tremendous level of severity with a 30% deviation from mean precipitation. Other shorter droughts occurred between A.D. 524 and 540 and between A.D. 636 and 645. A pluvial period seems to have occurred between A.D. 602 and 635 (Shimada 1991:261).

This climatic data was correlated with hard archaeological evidence from Moche sites and a number of inferences were made regarding the effects such extreme meteorological events may have had on Moche settlement patterns, systems of leadership, and subsistence patterns. Shimada and her team believed that a shift towards drought-resistant cultigens would have been necessitated by extreme climatic shifts; torrential El Niño rains on an already hyper-arid north coast would have caused flash flooding and increased soil erosion and would have contributed to new and greater sand dune sources at the mouths of rivers. With the deteriorating environment, the elite at Moche may well have lost prestige and power, allowing previously oppressed polities like the Lambayeque to reclaim their former prestige and political leadership of the northern north coast (Shimada 1991:263).

Although one must concede that the Moche certainly were not the Tiwanaku and that any related inferences made from this study must be employed carefully, this study is rather relevant to my work for a number of reasons. First, the data gained by Shimada and his team, grounded in both archaeological and meteorological evidence, gives some indication of how a highly complex society, in the face of extreme environmental duress, may be afflicted and attempt to adjust. Evidence of shifting settlement patterns, subsistence patterns, and elite control provides tantalizing analogues for my interpretation of the decline of the Tiwanaku polity. Second, this study provides concrete evidence that extreme climatic fluctuations have occurred in the Andes in both the past and present; they may have been far more common-place than what scholars may have previously considered.

Limnological Evidence from Lake Titicaca

A recent study (Abbott et al. 1997) has demonstrated that the water levels of Lake Titicaca Basin have fluctuated dramatically over the last three and a half millennia. Sediment cores were extracted from the southern basin of the lake and then dated using both accelerator mass spectrometer and radiocarbon technologies. According to the study, when the water level of Lake Titicaca falls more than 10m BOL (below its outlet level) to 3,794 meters above sea level, two separate sub-basin lakes are formed. The eastern basin remains connected to Lake Titicaca proper by the Tiquiña Strait until the lake level falls more than 16m BOL and then the Titicaca system separates into three separate lake basins (Abbott et al. 1997:177).

The lake-level history of Lake Titicaca, based on the sediment samples extracted from its southern basin and subsequent dating methods, indicate that prior to 3,500 B.P., the lake level was lower than 15m BOL. Rising rapidly after 3,500 B.P., the lake level neared the overflow stage by 3,350 B.P. High accumulation rates present in certain sediment cores suggest large-scale erosion and the reworking of shorelines (Abbott et al. 1997:177). Between 3,300 and 2,900 B.P., the water level appears to have been rather variable in nature, fluctuating between the overflow stage and 8m BOL. After 2,900 B.P., the lake level apparently rose to within 2m of, and possibly above, the overflow stage although by 2,400 B.P. the water level again dropped to between 10 and 12m BOL. The lake level then increased abruptly to at least 2m BOL by 2,200 B.P., a period that saw the emergence of the Tiwanaku polity in the Lake Titicaca Basin. Sediment samples extracted from different sites in the basin experienced marked erosion during this low stand. After 1,900 B.P., the lake level fell between 10 and 12m BOL (Abbott et al. 1997: 177). Shallow-water subfacies indicate that the lake level rose after 1,650 B.P. to near the overflow level. The latest prolonged low stand began at about 900 B.P. and culminated after 700 B.P., a date corresponding to the terminal stages of Tiwanaku society and the rise of smaller local Aymara kingdoms in the basin. Dropping between 7 to 12m during this period, it was not until after 500 B.P. that water levels began to return to their present levels (Abbott 1997:179).

This limnological study indicates that the water levels of Lake Titicaca, over the last 3,500 years, have been in near constant flux, wavering nearly 22m in amplitude (Abbott 1997:179). The most crucial periods of study, dating post-2,200 B.P. and entailing a Tiwanaku presence in the region, provide little reassurance of stable water levels, a necessity for a people that apparently relied so heavily upon agricultural technique like terraced fields, raised-fields, and qocha basin systems.

According to Erickson (2000:18), a lake level change of 1 meter can either inundate or expose approximately 120,000 hectares of land surface. This figure is staggering in that during prolonged periods of severe drought,

enormous tracts of land would have been exposed and susceptible to the processes of salinization, a situation reminiscent of the Aral Sea case study (Williams 1999) mentioned earlier.

COULD SALINIZATION HAVE OCCURRED IN THE LAKE TITICACA BASIN?

The unsustainable {modern} use of resources in the Lake Titicaca Basin has resulted in deforestation, extensive erosion, river sedimentation, soil salinization, silting up of lakes and water imbalances in watersheds, all contributing to extreme variations in water flows (Jellison et al. 2004:11).

As stated by Williams (1999:85), salinization is “mainly restricted to endorheic drainage basins in semi-arid or arid regions of the planet.” The Lake Titicaca Basin is undoubtedly endorheic and precipitation in the basin varies from 1000 mm/year in the mountains to the north and in the middle of the lake, to 200 mm/year in the southern part. This phenomenon, combined with the region’s geological characteristics, causes a pronounced salinization gradient of the waters from north to south reaching 100 g/L in the southern part of the Poopó Lake (BAALT 1992:2). Lake water has a slight yet distinctly salty taste and freshwater organisms are osmotically quite sensitive (Kolata 2003a:178). The water quality is good in the tributary rivers of Lake Titicaca, while the more salinized water to the south limits its use for irrigation purposes, needing flow regulation in the dry seasons and demanding also an appropriated drainage. It is conceivable that this salinization gradient (contingent on modern precipitation patterns) could have been exacerbated or augmented by reduced precipitation rates or prolonged periods of drought, a phenomenon that did indeed occur in prehistory as described in the preceding section. See Figure 4 for a closer look at the fluctuations in precipitation levels through time in the basin. According to recent tests the surface water of the lake possesses a pH of about 8.6 (ILEC 2001); by comparison, seawater possesses a pH of between 7.8 and 8.3. It is conceivable that periods of prolonged drought in antiquity may have altered the pH of the lake waters, possibly rendering them nearly as salinized as seawater.

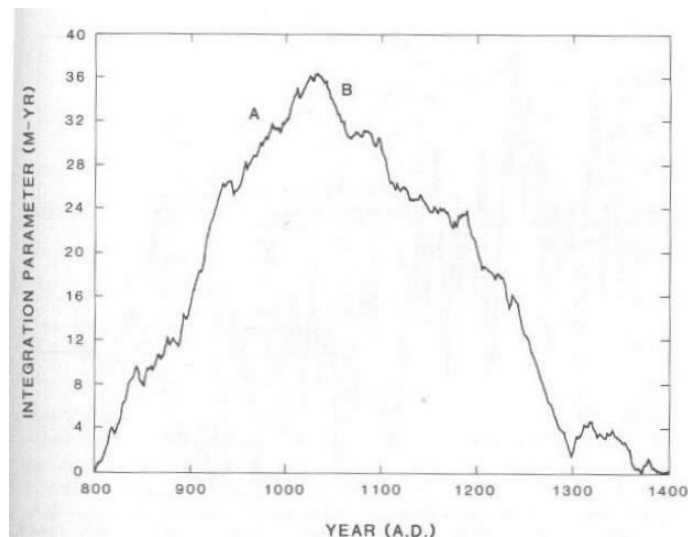


Figure 4. Graph displaying precipitation fluctuations over a six-century period in the Lake Titicaca Basin.

Figure taken directly from Kolata 1993:289

According to Goldsmith (1984), another hallmark of regions afflicted with salinized soils is a relatively high rate of evaporation. The Lake Titicaca Basin, without coincidence, displays this characteristic. The average water volume balance of the lake shows the importance of the evaporation factor (over 90% of the output in the balance) and the difficulty to regulate the lake’s water level only with the control of its discharges by the Desaguadero River (less than 5% of the output in the balance). It does not require a stretch of the imagination to believe that the extraordinarily high evaporation rate witnessed today may have been even more dramatic in the prehistory during drought episodes, a phenomena that could have greatly stressed the hydrological cycle of the basin.

Williams states that “the most important human activities in the process of salinization in water bodies are the clearance of natural vegetation (deforestation) and irrigation” (Williams 2001:89). Both of these anthropogenic activities occurred not only in the present but there is compelling evidence indicating that they also occurred in prehistory. According to a study by the Binational Autonomous Authority of Lake Titicaca, until approximately the

year A.D. 1000, the high plateau was covered with a native tree forest (*Polylepis sp.*). Around the year A.D. 1100, a severe eighty-year drought changed the surface cover and the forest disappeared (BAALT 2002:471). Clark Erickson (2000:320) posits that this deforestation can just as easily be attributed to Pre-Columbian human degradation as to long-term climatic change. Even today the whole catchment area on the high plateau of the Altiplano remains almost treeless; woody vegetation currently covers approximately 25 square kilometers, less than .5% of the total catchment area. Herbaceous vegetation, by comparison, dominates over 36,000 square kilometers, nearly 75% of the catchment region (ILEC 2001).

This case of prehistoric deforestation, an occurrence that still affects the natural equilibrium of the region today (Kolata 2003a:248), may have conceivably compounded pre-existing factors leading to the salinization of soils in the basin. According to Clark Erickson (2000:330), Andean soils are highly susceptible to erosion, much of which is due to human activities. Today in the basin the major part of farm activity is directed to animal husbandry (cattle, sheep, llamas, and alpacas) whose mismanagement causes a deterioration of the grazing areas. With the passing of centuries, the vegetation coverage is diminishing due to the use of its species for firewood and to the overgrazing of its pastures causing a major erosion of the soil (BAALT 1992:2).

It is obvious that the Lake Titicaca Basin possesses many of the hallmarks of traditional ecological systems afflicted with salinization. From its status as an endorheic hydrological system, its natural salinity gradient, its high evaporation rate, and its long history of deforestation, irrigation and soil erosion, the modern ecological status of the region may serve as an analogue for comparison with the prehistoric occupation of the basin. Modern inhabitants of the region have induced a great deal of environmental degradation and the ancient inhabitants of the basin could have done the same.

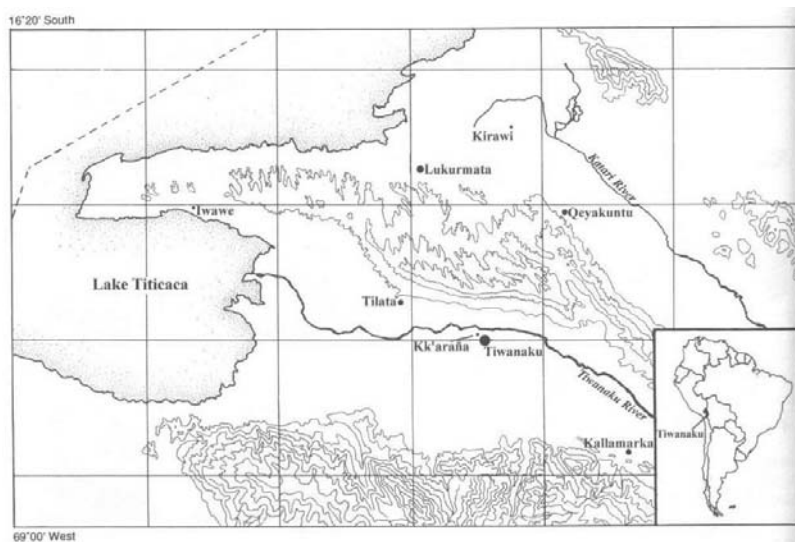
SIGNS OF SALINIZATION IN THE LAKE TITICACA BASIN

Archaeological Correlates from La K'araña

La K'araña is a locally-named sector within the Tiwanaku site, located directly north of Tiwanaku's monumental core (see Figure 5). In 1988, Max Portugal found architectural remains in this area and evidence of domestic activity. The discovery of polychrome painted bricks, located elsewhere in elite sectors of the Tiwanaku site, have led some scholars to speculate that this sector may have served as a residence for some of Tiwanaku's high status populations (Kolata 2003b:316). North of La K'araña, a plain extends toward the Tiwanaku River, where Proyecto Wila Jawira organized the rehabilitation of raised fields. This extensive plain could explain the toponym *La K'araña*, which is similar to the Aymara word "kara", meaning barren. Kolata believes that the toponym may also mean "a place of rest", possibly referring to the numerous burials known to exist there (Kolata 2003b:316). I, however, believe that the Aymara peoples who have inhabited the area since the collapse of the Tiwanaku state were quite literal when they bestowed up this land a name signifying "barren."

Figure 5. Map displaying the relative location of the La K'araña sector in relation to the city of Tiwanaku.

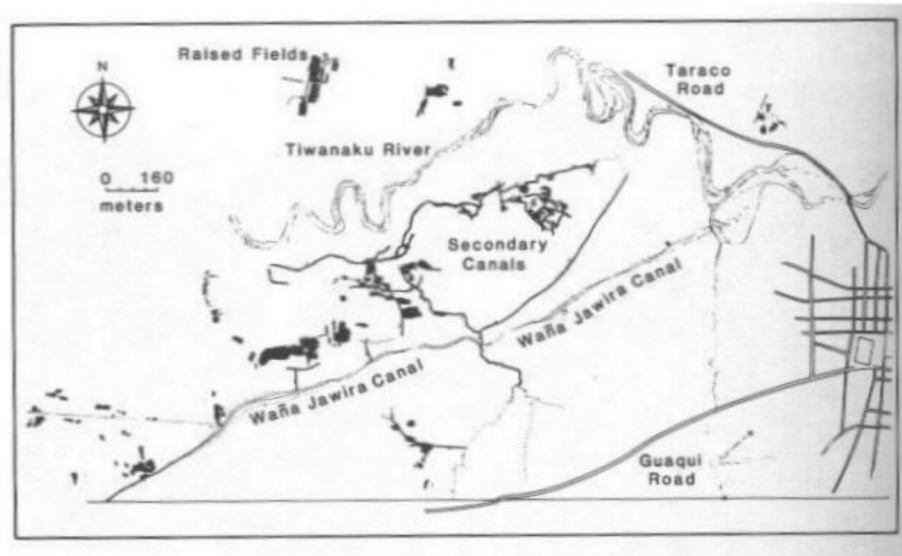
Figure taken directly from Kolata 2003b:xxxiii



A sample extracted from this section yielded a dark gray, compact, clayey soil with high organic matter content. Granulometric analysis revealed the following texture: 8% sand, 37% silt, and 55% clay (Kolata 2003a:81). The sector's soil, like many other parts of the region, exhibits "significant human alteration" (Kolata 2003a:83).

Figure 6. Map displaying extensive canal usage in the Tiwanaku Valley

Map taken directly from Kolata 1993:226



Archaeologists working in this sector located numerous drainage canals in association with the La K'araña storage complex. The canals descended from the monumental sector of the city, indicating that some of the water originated in or circulated through the city's ceremonial core. Given the slope and orientation of the canals, they probably were intended, in part, to irrigate the plain north of the sector where ancient and rehabilitated raised fields exist today (Kolata 2003b:325). La K'araña's drainage features, some believe, most likely articulated with the monumental framework of surface and subterranean canals that form an elaborate infrastructure of water control in the elite, civic-ceremonial core of the city (see Figure 6 above). According to Kolata (1993:226), "The enormous canal of the middle and lower Tiwanaku Valley speaks volumes regarding the organizational and design skills of the Tiwanaku elite to *reshape* their natural environment." Perhaps the most telling fact remains that La K'araña's canals were lined with stone and caulked with clay, indicating that they were "clearly designed for the efficient transport of fresh water" (Kolata 2003b:326). As introduced in an earlier section, the act of lining canals is a costly step sometimes undertaken in the modern era to reduce the seepage of salinized water into surrounding soils (Eilers 1995:8).

As stated by Kolata (2003a:88), one of the most important irrigation characteristics of water quality from the frame of reference of irrigation is the total concentration of soluble salts. In general, taking into account all existing ions, total soluble salt concentrations that exceed 1 gram/liter are considered deleterious to irrigation agriculture. From the data collected by Kolata and his team (presented in Table 1), it is quite evident that samples collected from a spring in the La K'araña sector (Station 3) possessed a salt concentration exceeding the standard limit of 1 gram/liter of total soluble salts. Interestingly, stations 4, 7, and 10 also exhibited slightly higher total salt concentrations than the other stations (Kolata 2003a:88). Figure 7 contains a map of the locations of these stations. Apparently some of the soils found in both the Tiwanaku and Rio Catari basins, displayed in the aforementioned figure, possess a strong salt content and, in some cases, are stated as being sodium-saturated (Kolata 2003a:80).

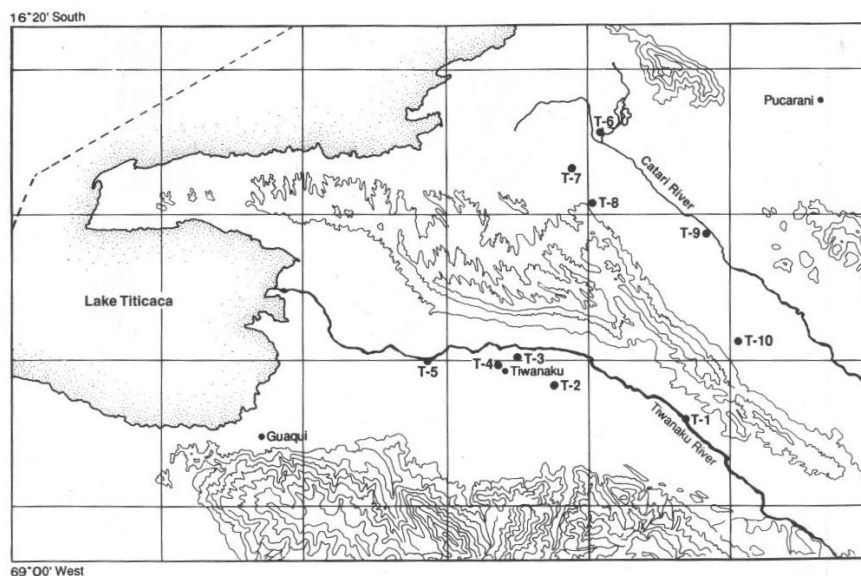
Table 1. Table listing the Total Salt (TS) concentrations of water samples from 10 stations in the Tiwanaku and Catari River basins.

Station	Grams/Liter
1	0.554
2	0.501
3	1.005
4	0.877
5	0.557
6	0.602
7	0.762
8	0.555
9	0.587
10	0.960

Table taken directly from Kolata 2003a:88

Figure 7. Map conveying the locations of water samples taken from the Tiwanaku and Catari basins.

Map taken directly from Kolata 2003a:86



During the farming of reconstructed experimental fields in the Tiwanaku Valley, the lowest yields in the entire valley came from the La K'araña sector. The raised fields in this area achieved a gross yield of 6.3 mt/ha and a net yield of 3.82 mt/ha. The K'araña fields, for some reason, exhibited an unusual state of retarded growth and susceptibility to hail and frost. The lower yields were attributed by Kolata and his team to a period of increased vulnerability—caused by a delay in the planting of fields during a crucial part of the season—to hail and frost (Kolata 2003a:215), however, I believe the true reason to be an enduring state of salinization in the basin.

Evidence in Tiwanaku Cultigens

One of the key indicators of the possibility of soil salinization in the Lake Titicaca Basin is provided by a marked shift in subsistence strategies during the Tiwanaku occupation of the region. The first cultigen upon which I wish to focus is quinoa, known scientifically as *Chenopodium quinoa*. In the harsh climate of the Altiplano region, nearing 13,000 feet in elevation and prone to debilitating frosts as well as severe droughts, few crops can be grown in these marginal areas. One of them, quinoa, can be cultivated under extreme conditions of salinity, drought, and cold (Jacobsen 1999: 404), growing best at a soil pH between 5.5 and 8.0.

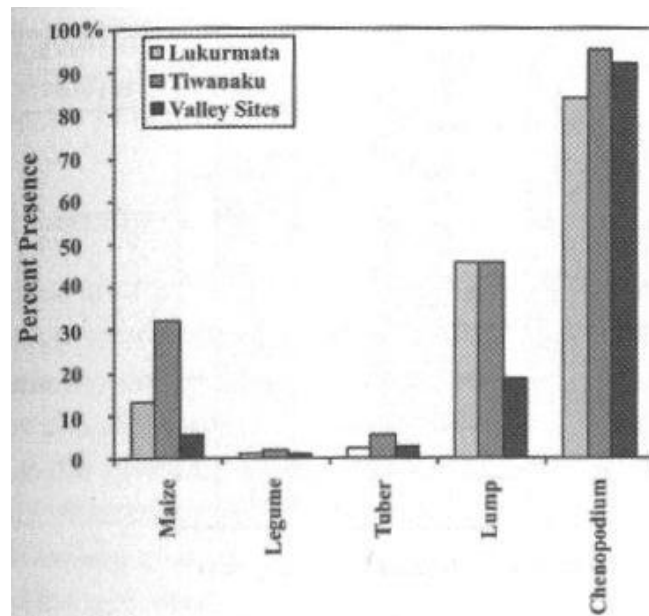
According to Kolata (2003b:391), *Chenopodium* ubiquity is extraordinarily high throughout the cultural phases at Tiwanaku, ranging from a 92% to a 99% presence (see Figure 8). *Chenopodium* density is particularly high during the Tiwanaku IV phase (A.D. 400-800), followed by a very slight reduction in the Tiwanaku V phase (A.D. 800-1200). The strong presence of *Chenopodium* in the archaeological record was largely unexpected by Kolata

and his team; in order to account for its undeniable existence at Tiwanaku sites, a number of theories were posited. Kolata (2003b:392) states the following:

Whereas legumes, tubers, and Chenopodium all thrive at cold, high altitudes, Chenopodium, because it is significantly more halophytic than the other food crops, is able to grow well in saline soils. Thus, a change in the relative proportions of these crops may reflect increasing salinization of agricultural fields, or a change in the location of agricultural production to areas with more saline soils over time. Salinization could be linked to prolonged drought, which would reduce the influx of sweet waters into raised-field complexes and allow salty lake waters to dominate.

Figure 8. Graph displaying the ubiquity of Chenopodium at Tiwanaku sites across the Lake Titicaca Basin.

Figure taken directly from Kolata 2003:389.



In a comparative study, Jacobsen and his colleagues (2000) tested the salt tolerance mechanisms of two varieties of quinoa and one variety of amaranth. Amaranth demonstrated very little ability for the regulation of leaf water potential and stomatal conductivity, and the plants died at high salinity levels. Quinoa, on the other hand, behaved as a facultative halophyte, accumulating salt ions in its tissue. This accumulation of salt indicates that quinoa may be used to clean salt-contaminated soils (Jacobsen 1999:403).

The second cultigen I wish to discuss is barley, known scientifically as *Hordem vulgare*. Shannon (1997:89) states that barley is one of the most salt-tolerant grains and forage crops known, like quinoa, thriving at a soil pH between 5.5 and 8.0 (Valenzuela and Smith 2002:1). In wheat, sorghum and oats, ear emergence, anthesis, and grain maturity occur earlier under saline conditions, whereas, in barley and rye maturity is unaffected by salinity. This resistance to highly salinized soils has made the cultivation of barley particularly appealing throughout history in regions where secondary (human-induced) salinization has seriously hindered the productivity of other less tolerant cultigens. According to Shannon, there is evidence that farmers first dealt with salinity by replacing salt-sensitive crops with more salt-tolerant ones; for example, barley replaced wheat in early Ethiopia (Shannon 1997:76). This shift, some Middle Eastern scholars believe, occurred even earlier in another part of the world. Dickson (1987:714) mentions the work of Jacobsen and Adams (1958) and their contention that Sumerian farmers reduced their planting of wheat in favor of a greater and greater reliance on more salt tolerant crops such as barley in the centuries that followed the construction of the Tigris canal, an anthropogenic action that may have led to increasing soil salinization and greater socio-political stress in the Fertile Crescent.

Although barley was not cultivated by the Tiwanaku polity in antiquity, its popularity amongst farmers in the region today may allow us to make inferences regarding the past and present soil conditions of the basin. According to Kolata (2003a:209-210), in the Tiwanaku region today, the common sequences in a given field over a three-year period are potato-potato-barley, potato-quinoa-barley, and potato-barley-barley. The fact that barley is present in

each of those sequences, interspersed with other cultigens (some of which are quite salt-tolerant as well: quinoa), may indicate that the soil, even today, possesses elevated salt levels and may have exhibited similar levels in prehistory.

Evidence in Changing Settlement Patterns and the Abandonment of Raised Fields

Tiwanaku agricultural systems in both the Altiplano core territory and its coastal outposts reflect consummate skill in conception and construction. (Kolata 2003a:194)

Current archaeological evidence indicates that from 3,500 to 2,000 years ago (Formative Period—Tiwanaku I phase), the population in the Tiwanaku hinterland was distributed in some 40 to 60 hamlets and villages representing from 10,000 to 15,000 people (Kolata 2003b). Many of the settlements are located on or near the current shoreline of Lake Titicaca or in closely adjacent uplands, although a profile of the complete population size and distribution of this period cannot be introduced with great confidence or accuracy due to the fact that small Formative Period sites may be deeply buried under sediments in the active floodplains of the river basins and therefore missing in survey samples (Kolata 2003b). The period between A.D. 200 to 900 (Tiwanaku II—Tiwanaku IV phases) witnessed significant processes of population aggregation and urbanization. It was at this time that substantial populations concentrated at Tiwanaku and other regional urban centers such as Lukurmata, Pajchiri, and Khonko Wankané (Kolata 2003b).

According to Binford et al. 1997, human settlement patterns in the Lake Titicaca Basin indicate that the major period of construction and use of raised fields occurred in the late Tiwanaku IV and Tiwanaku V periods (approximately A.D. 600-1100). During these periods, most settlements in the Catari Basin occurred in nucleated centers surrounded by raised fields and linked by roads and elevated causeways. After the collapse of the Tiwanaku state (A.D. 1000-1100), settlements consisted of small (<1 hectare) dispersed occupations having no direct association with the raised fields. This pattern is apparently repeated in the Tiwanaku valley to the south and in area of Tiwanaku-related raised fields in the Juli-Pomata region of Peru (Binford et al. 1997: 243). In the middle Tiwanaku Valley alone, a nearly 60% decrease in population is represented by a dramatic reduction in the number of sites dating from the transition of the Early Pacajes (Post-Tiwanaku) period to an Incan intrusion in the basin (Kolata 2003b:124).

Given all that has been said regarding the gradual abandonment of raised fields and the long-held notion of tremendous raised field productivity, it seems inconceivable that raised fields could have been so thoroughly abandoned in antiquity. If they were so agriculturally viable, so productive, why was usage almost non-existent following the collapse of the Tiwanaku state and never again adopted on a scale a fraction as large as during the Tiwanaku IV and V phases? This suggests a number of possibilities, one of which includes the possibility that raised field systems were not nearly as productive as traditionally believed by Andean scholars as well as the possibility that perhaps indigenous populations were not as dependent upon this type of agriculture as has been assumed by many experts.

NEMATODES AND THE INEFFICIENCY OF RAISED FIELDS

The Myth of Raised Field Supremacy

It has only been within the last year or so that the myth of raised field agriculture as a sort of utopian subsistence system has been called into question. Bandy (2005) raises a number of arguments regarding this subsistence technique, questioning both the efficiency of raised field systems and postulating reasons for what he asserts is a relatively low level of productivity.

A brief physical overview of raised fields would likely prove helpful to the reader. Clark Erickson (2000:333-334) provides an excellent description of raised field systems found in the Lake Titicaca Basin. He states the following:

Raised fields are large elevated planting platforms constructed in areas of waterlogged soils or soils prone to annual flooding. The platforms are accompanied by canals or ditches on one, two, or all sides that were created during the process of raising the field. Raised fields are highly variable in size and shape. Platforms range from 4 to 10 meters wide, 10 to 100 meters long, and from 0.5 to 3 meters tall. Canal size is generally in proportion to the size of the platform. Bundles of fields are organized in regular patterns, possibly reflecting the social organization of agricultural labor and land tenure, specific functions or crops, or stylistic preferences. A conservative estimate of area of Pre-Hispanic raised field agriculture is 120,000 hectares.

In order to truly appreciate the gravity of Bandy's work, one must first realize the monumentality of what he has called into question. For the last quarter century or so, since the first experimental fields were constructed around Lake Titicaca in both Peru and Bolivia by indigenous peoples under the direction of Andean archaeologists, raised fields have been touted as a subsistence technology capable of generating boundless yields, at least in comparison to the yields obtained from *wacho* dry bed farming. Impressive initial yields, two to four times the average obtained by traditional techniques, led to a great deal of excitement in both the world of Andean archaeology and a surge of publicity and funding from outside parties. Archaeologists like Alan Kolata and Clark Erickson quickly imbued raised fields with incredible attributes, claiming they required almost no fallow period between periods of cultivation and, perhaps even more fantastically, that raised fields were capable of producing two harvests of potatoes within a single agricultural season (Bandy 2005:273). In the eyes of many Andean scholars, raised fields possessed few, if any, discernible weaknesses and represented a sort of utopian subsistence technique from the past, destined to dramatically improve the lives of indigenous peoples in the present. As romantically intoxicating as that fantasy may have seemed, it was, for the most part, without merit.

After the unprecedented success of the first reconstructed raised fields in the Lake Titicaca Basin, millions of dollars of domestic and foreign developmental funds were invested in the rehabilitation of prehistoric field systems and the construction of new systems following the ancient designs (Bandy 2005:274). Interest in raised fields was at its peak. Sixteen organizations in Puno, Peru were engaged in the construction of field systems and between the years of 1981 and 1994, more than 1,000 hectares of raised fields were constructed in that province alone. By the year 2000, more than 2,000 hectares, involving 3,350 families and 420 *campesino* organizations, had been rehabilitated (Bandy 2005:274). Despite an enormous initial interest in prehistoric field systems and the backing of millions of dollars and numerous organizations, raised fields undeniably failed. Swartley (Bandy 2005:274; Swartley 2000:213) recalls that in 1994 many of the raised fields were beginning to be abandoned and that by 1996 all of the raised fields had been abandoned. Equally interesting is the fact that many of the major organizations created to aid in the reconstruction and rehabilitation of the fields systems are now virtually all defunct (Bandy 2005:274). Bandy succinctly states that:

Raised field agriculture has emphatically **not** been adopted in any significant way by the *campesinos* of the contemporary Lake Titicaca Basin, despite ample funding, international enthusiasm, and over a decade of systematic promotion (Bandy 2005: 274).

My conclusion, then, is this: raised fields were probably always somewhat less efficient than dryland agriculture, and may have been considerably less efficient (Bandy 2005: 286).

The stagnation of the reconstructed raised field systems, surprisingly, never really gained as much press as their early period of success and the myth of *waru waru* supremacy remained firmly in place for a number of years, rarely scrutinized by Andean scholars. Although a number of theories have emerged regarding the relative failure of the fields systems in Peru and Bolivia, some blame the indigenous workers; others fault the Andean archaeologists heading the projects and their field designs. Another hypothesis, excluding the human factor, has been proposed by Matthew Bandy.

Bandy's Nematode Hypothesis

Bandy speculates that nematode populations, more specifically the species *Globodera rostochiensis* (the golden nematode) and *Globodera pallida* (the white nematode), are to blame for the stunted plant growth and the marked decline in yields witnessed in the reconstructed field systems. These nematodes attack the roots of potato plants and in sufficient densities interfere with the ability of the plants to absorb water and soil nutrients, in the process stunting plant development and dramatically reducing yields (Bandy 2005:276). It should be noted that it can take up to 20 years from the time these nematodes are introduced into a country before they are detected and approximately 6 to 7 years from their introduction before they even reach a detectable level (Berg 1999:3). Once present in the soil, the only real way to counteract the devastating effects of these nematodes, to completely eliminate them from the soil, is to abandon cultivation of the fields, to allow them to remain "fallow" if you will. *Globodera rostochiensis* demands as much as a decade of inactivity while *Globodera pallida* necessitates nearly two decades. Apparently, shorter fallow periods or the rotation of potatoes with non-host crops can reduce the population density of these nematodes to acceptable levels (Bandy 2005:276).

The high yields reported by Erickson and Kolata, Bandy asserts, were due to the initial lack of plant-parasitic nematodes in reconstructed and rehabilitated fields. It is my contention, however, that the impressive yields

achieved by the early experimental fields do not accurately portray the true productivity of raised field systems; rather, they may simply indicate that even at that time some degree of salinization was afflicting the soils of the basin. After all, one of the early signs of soil salinity, mentioned in an earlier section, is a surge in crop growth (Eilers 1995:1). Following the decline and eventual collapse of the Tiwanaku polity—the last people to extensively farm the region—areas of raised fields were not used for decades or even centuries at a time. These prolonged fallow periods could have diminished nematode populations to extremely low levels although it should be remembered that they never really would have left the soil. They may have simply been lying dormant, experiencing a state of inactivity until conditions were right for a population explosion. Swartley (Bandy 2005:277; Swartley 2000:175) was told by her informants in Bolivia the following:

In all cases farmers recounted “normal,” “good,” or “very good” production in the first year of community-level raised-field cultivation (1990-91). According to farmers, the fields produced so well that this was stated as the primary reason for expanding...raised fields...in the following agricultural years (1991-92). Yet in each case, production dropped dramatically in the second year, producing “very little,” “not very good,” or “average” crops of potatoes...By the third year all of the raised fields produced a very poor harvest...so that only a handful of residents were prompted to plant a fourth year of potatoes.

According to Bandy (2005:277), Swartley admitted that “across the Lake Titicaca Basin, farmers discontinued cultivating individual fields after two to four agricultural seasons.” Bandy believes that the declining productivity of field systems around the basin and the subsequent abandonment of those systems can be attributed to booming *Globodera spp.* nematode populations. This conjecture raises a number of questions in and of itself. For instance, why were nematode populations able to expand so quickly following the construction of the field systems? From Bandy’s statements in the preceding sections, that “raised were probably always less efficient,” one must assume that nematode populations, even in prehistory, ravaged agricultural systems in the Lake Titicaca Basin. This assumption of continuance is crucial to my theory of why nematode populations, especially during the Tiwanaku occupation of the basin, may have flourished.

The Correlation between Salinization and Nematode Populations

What is it about potato cyst nematodes that may have allowed them to flourish in a tremendously harsh landscape like the Altiplano? Due in large part to the sheer size of the phylum Nematoda—approximately 500,000 species (Dufour 1998:1)—little is yet known about each species’ specific characteristics pertaining to their optimal habitats, biological controls, and preferred hosts. Despite this impediment, a number of hypotheses can still be addressed using more researched nematode species as analogues for species like *Globodera rostochiensis* and *Globodera pallida*, species upon which little research has been conducted regarding saline tolerance and associated ecological durability. Many of my conclusions regarding the interaction between soil salinization and potato cyst nematode populations were derived in this manner.

According to Spears (1968:3), of all the crop pests worldwide, the potato cyst nematodes *Globodera rostochiensis* and *Globodera pallida* are among the most difficult pests to control. Once established, they are difficult to eradicate because potato cyst nematodes have one of the highest survival values for any organism and can survive for over 30 years as eggs protected by a durable cyst wall. In addition, the build-up of nematode populations is slow and their presence is not easily detected; once their populations increase to high levels, drastic crop losses often occur (Spears 1968:4). The sheer resilience of potato cyst nematodes indicates that even under extreme environmental stress, they possess the capacity to endure while other, less resilient organisms may not.

Interestingly, some species of root-knot nematodes (*Meloidogyne spartinae*) and sting nematodes (*B. maritimus*) may be well adapted to high salinity conditions (Hixson et al. 2005: 38). Due to a number of similar characteristics, root-knot nematodes may serve as an adequate analogue from which to make inferences regarding the interaction between potato cyst nematodes and soil salinization. It should be noted that *Globodera rostochiensis* was classified as *Heterodera rostochiensis* until at least the publication of Jenkins and Taylor (1967); equally interesting is that until 1949 the root-knot nematodes, *Meloidogyne spp.*, were also included in *Heterodera* under the name *Heterodera marioni* (Jenkins and Taylor 1967:87). Due to their past placement in the same family, the two species of nematodes undoubtedly share a number of physical and ecological attributes. Like potato cyst nematodes, root-knot nematodes can persist in adverse conditions for long periods of time by forming durable cysts (Olsen 2000:1). In addition, root-knot nematodes are extremely difficult to control once introduced into a given geographical area: summer dry fallow will reduce the nematode populations in soils but will not eradicate them (Olsen 2000:2). From these shared traits, I have surmised that indigenous potato cyst nematodes, like root-knot nematodes in other parts of

the world, may be adapted to highly salinized environments, ecological settings that I believe may have been prevalent in the Lake Titicaca Basin in antiquity.

Some natural predators of nematodes include bacteria, fungi, mites, amoebae, and flatworms. One specific nematode predator, the nematophageous fungus *Hirsutella rhossiliensis*, has exhibited a negative correlation with soil pH. In laboratory experiments, the maximum activity exhibited by the fungus occurred at a pH of 4.5 while activity gradually declined to near zero as the pH increased to 6.5 (Jaffee and Zasoski 2001:324). This data is significant because potato cyst nematodes like *Globodera pallida* exhibit a positive correlation with soil pH. One study examined the effects of varying pH levels on potato cyst nematode populations and their ability to decimate potato crops. Results indicated that nematode damage was higher at a pH of 6.1 than at a pH of 4.8 (De Ruijter and Haverkort 1999:61). Not coincidentally, root-knot nematodes—members of the family *Meloidogyne*—hatch particularly well in soils with a pH ranging from 5.0 to 8.0 (Zuckerman et al. 1971:274). From this data one can infer that potato cyst nematode populations may be capable of thriving in environments that are ecologically unsuitable for the proliferation of some nematode predators.

How would the soils of the basin have achieved a higher pH? According to the Manitoba Agriculture Soil Fertility Guide (2001), higher pH soils may result from erosion, tillage, or land leveling which removes or dilutes surface soil with more calcareous subsoil and from salt movement or salinity in the soil. During my earlier discussion of the Lake Titicaca Basin and the various anthropogenic disturbances that have occurred in both the past and the present, erosion has certainly been one of the most prominent. The alteration of indigenous soil structures in prehistory may have in turn adjusted the pH of the basin's soils, another reflection of increasing soil salinity. It is my assertion that increasingly salinized soils in the basin may have presented an environment more amenable to the propagation of potato cyst nematodes.

RESULTS AND CONCLUSIONS

My research has led me to the following conclusions. First, it is apparent that periods of prolonged drought occurred in the Andes, as evidence by ice core studies from the Quelccaya Glacier (Shimada 1991) and limnological studies from the Lake Titicaca Basin (Abbott et al. 1997, Binford et al. 1997). These drought episodes drastically affected the course of the Moche and Tiwanaku civilizations. In addition, as stated by Williams (1999:85), increasing climatic aridity, a hallmark of extreme drought, may also aid in the salinization of a given ecological setting. The aforementioned drought episodes may have provided the impetus for an increasing salinization of the Lake Titicaca Basin.

Secondly, from the works of Williams (1999, 2001) and Goldsmith (1984), one can infer that salinization is a major problem worldwide, especially in areas of great ecological stress caused either by natural or anthropogenic processes. Many of the hallmarks of regions afflicted with salinization today are present in the ecological settings of the Lake Titicaca Basin in the present. One must believe that centuries ago, at the height of its Tiwanaku occupation, the region likely exhibited many of those same characteristics. From a comparison of a number of case studies provided by Williams (1999, 2001) and geological and hydrological information provided in the works of the BAALT (1992, 2003), I am able to state that the Lake Titicaca Basin is, in fact, a natural setting for soil salinization. Its endorheic status, its periods of fluctuating precipitation, its high evaporation rate, its history of prolonged drought, and its history of anthropogenic disturbance make such conclusions possible.

Third, from the work of Matthew Bandy (2005) a new conception of raised field agriculture in the Lake Titicaca Basin emerges. Long considered a highly productive form of agriculture, it is now evident that that notion is in desperate need of reevaluation. From the collapse of experimental field programs in the basin to eye-witness accounts of infertility by indigenous farmers, it is apparent that raised fields were likely never as productive as traditionally touted by Andean scholars. Furthermore, the astounding early yields attained by experimental raised fields may not reflect the true productive potential of raised fields systems; if anything, they may hint at a growing salinization of indigenous soils. From this work also emerges a vehicle for that documented inefficiency, the potato cyst nematode species *Globodera rostochiensis* and *Globodera pallida*. These parasitic pests are resistant to even the most inhospitable conditions, they are extremely difficult to eradicate, and they are able to inflict enormous damage once present in sufficient numbers.

Fourth, it is my contention that nematode populations may have been able to thrive and even spread in the raised field systems of the basin due to an increasing salinization of indigenous soils. Brought about by a combination of climatic stress and anthropogenic modification, these salinized soils may have presented an environment that was more favorable for potato cyst nematodes and less favorable for their natural predators. In time, as nematode populations gained a greater foothold in the region, raised fields may have become increasingly unproductive and eventually abandoned in favor of other subsistence techniques. The abandonment of raised fields,

in turn, undermined the sociopolitical and sociocultural fabric of Tiwanaku society, initiating an era of cultural decline.

Like a fallen house of cards, the Tiwanaku state was eroded away in piecemeal fashion, the victim of a sort of ecological domino effect. Episodes of extreme aridity combined with the indigenous alteration of the natural environment to bring about salinization, a process which in turn may have allowed indigenous nematode populations to proliferate and devastate the agricultural systems that fueled the Tiwanaku polity. As I stated earlier, no indigenous culture in the Andes—no matter their level of sophistication—has ever been exempt from either the mercurial nature of the surrounding environment or the consequences of its alterations to that environment. The Moche certainly were not and it is safe to say that neither were the Tiwanaku.

ACKNOWLEDGMENTS

I would like to thank Professor James Theler for his tremendous patience during the formation of this work. His scrutiny and advice were invaluable in all stages of the creative process; without his help none of this would have been possible. I also wish to impart my deepest gratitude to Professor Timothy McAndrews. The focus of this paper, the possible salinization of the Lake Titicaca Basin, should be credited to him alone. Thankfully, he allowed me to pursue this intriguing hypothesis independently and like so many other faculty members, he was always ready to address any questions or issues I may have had along the way. Lastly, I wish to thank Dr. Constance Arizigian. There were many moments of stagnation during the construction of this paper, times when I simply believed the subject had exhausted itself and wasn't worth further pursuit. Connie was always there to lend words of encouragement and always willing to contribute fresh ideas. I cannot overstate my thanks to all others involved, directly or indirectly, in the creation of this work. Thank you all for your support and assistance.

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