Farmers' Experience and Knowledge: Utilizing Soil Diversity to Mitigate Rainfall Variability on the Taraco Peninsula, Bolivia

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As many chapters in this volume demonstrate, unpredictable rainfall is a common reality for farmers worldwide, past and present. During my ethnographic study of farming practices among indigenous Aymara communities on the Taraco Peninsula, Bolivia, I had many conversations about rain. When I arrived in October 2003, the farmers said the planting season was delayed because the rains had not yet come. When the rain finally fell in November, they complained that it was too much. Despite anxiety voiced about too much or too little rain, I found that the Taraco farmers have practices that mitigate risks presented by variability in precipitation. The previous chapters have provided examples of risk reduction strategies such as exchange, storage, and economic diversification. In this chapter, I take a detailed look at how farmers in the Lake Titicaca basin of the Andes reduce the risk of crop failure due to unpredictable rainfall through knowledge of the water-retention qualities of the local soils. Using this knowledge they have developed a planting schedule and land-use strategy that usually results in a successful harvest even in the face of drought or flooding.

Detailed, ethnographic study of generational farming practices that develop in response to short-term climatic variations are important for
investigators interested in responses to long-term or larger magnitude climatic events. The particular practices will often dictate whether a society can successfully adjust to the new conditions or not. While many of the chapters in this volume provide examples of how past societies dealt with large magnitude climatic changes, this chapter provides data for testing hypotheses about how the future farmers of the Lake Titicaca basin may respond to our current climate change predicament, but may also aid archaeologists in understanding how and why past inhabitants succeeded or failed in the face of climate change in antiquity.

**CLIMATE CHANGE AND FARMING IN THE LAKE TITICACA BASIN, PAST AND PRESENT**

Farming began in the Lake Titicaca basin (Figs. 8.1, 8.2) about 2000 years ago (Binford, Brenner, and Leyden 1996:95; Binford et al. 1997:242; Bruno 2006:43), approximately the same time that the current climatic regime and
Lake level were established (Baker et al. 2001:642; Tapia et al. 2003:160; Wirrmann 1992: 46; Wirrmann and Oliverira-Almeida 1987:320). Prior to this period, the lake basin was extremely dry and the lake may have dropped to 100 m below its modern level (Cross et al. 2000:30; Mounguiart et al. 1998:60; Rigsby, Baker, and Aldenderfer 2003:180; Rowe et al. 2002:194; Seltzer et al. 1998:169; Tapia et al. 2003:160; Wirrmann and Mounguiart 1995:352; Wirrmann and Oliverira-Almeida 1987:322). There is very little evidence for human occupation of the immediate lake basin during this time (Albarracin-Jordan and Mathews 1990:51; Bandy 2006:215; Lémuz-Aguirre 2001:13; Stanish et al. 1997:50).

While the basin has never returned to the extremely dry state it experienced in the mid-Holocene, the late Holocene climate has fluctuated...
between wetter and drier periods (Abbott et al. 1997). Lake cores taken by the Abbott team in Lake Wiñaymarka suggest there may have been extended dry periods from 2900–2800 BP, 2300–2200 BP, 1850–1650 BP, and 900–500 BP. Three of these dry spells fell in the Formative period (approximately 3500–1500 BP), and the last occurred at the end of the Tiwanaku period (approximately 1500–800 BP) (Table 8.1).

Archaeologists working in the Lake Titicaca basin are interested in understanding how these shifts affected human populations and their various economic activities (Binford et al. 1997; Janusek 2004:126; Rigsby, Baker, and Aldenderfer 2003:166). In particular, the Taraco Archaeological Project examines how these fluctuations impacted the prehistoric inhabitants of the Taraco Peninsula (Bandy 2001:140; Capriles Flores, Domic, and Moore 2007). In the following chapter, Moore examines zooarchaeological data to discuss changes in herding and fishing on the peninsula. As part of this team, I am interested in how these shifts may have affected agricultural production.

Currently, settlement (Bandy 2001) and archaeobotanical data (Bruno 2008; Whitehead 2007) demonstrate that agricultural production contributed to the Taraco Peninsula economy throughout the Formative period. In fact, the available archaeological data do not suggest abandonment of farming during the hypothesized dry periods. While this may suggest problems with the interpretation of the paleoclimatic data (Calaway 2005:784–86) and/or correlating them to the archaeological record (Bruno 2008:482–84), it may also indicate that farmers were able to adjust their farming practices to adapt to the shifting climatic conditions.

As part of my investigation of Lake Titicaca basin agriculture, I conducted a 13-month ethnoarchaeological study of modern-day Aymara farming communities on the Taraco Peninsula (October 2003 to November 2004). A major objective of this study was to document how the physical landscape and local climate shape agricultural land use. There are many differences between past and present Taraco Peninsula farmers, including crops, technologies, and even variation in the relative distribution of soils on the landscape. They do, however, share a very similar physical environment particularly in the basic geology of the peninsula, climatic regime, and shifting dynamic of the lake. Recognizing these differences and similarities, I suggest that it is possible to use relational analogy (Wylie 2002:147–48) to hypothesize about how past farmers may have reacted to long-term
<table>
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<tr>
<th>Lake Titicaca Chronology</th>
<th>Relative Climatic Conditions</th>
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<tr>
<td>Late Horizon (Inca/Pacajes)</td>
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<td>Late Intermediate Period (Pacajes)</td>
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<td>Middle Horizon (Twanaku IV-V)</td>
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<td>Middle Formative (Late Chiripa)</td>
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shifts in rainfall and lake level based on modern-day use of the landscape for agriculture.

In the following section, I describe the general characteristics of the climate in the Lake Titicaca basin with particular attention to the rainfall patterns and their effect on lake level. This description is pertinent to my discussion of farming practices and also provides the background to Moore’s chapter on the impact of shifting rainfall and lake level on herding and fishing during the Formative period.

CLIMATE OF THE ANDEAN ALTIPLANO
AND LAKE TITICACA BASIN

Lake Titicaca is located on the altiplano, or high plain, which extends between the eastern and western ranges of the Andes (Fig. 8.1). The altiplano is one of the coldest and driest regions of the Andes. The mean annual temperature ranges from 7º–10ºC (Montes de Oca 1995:363), with warmer temperatures in the austral summer (December, January, February) and cooler temperatures in the austral winter (June, July, August). Rainfall varies on a north to south gradient with an average of 800 mm per year in the northern basin and 200 mm per year in the southern basin (Vuille, Bradley, and Keimig 2000:12447).

Today, the altiplano, particularly the drier southern portion, is only suitable for camelid pastoralism and limited cultivation of cold and drought-tolerant crops such as the Andean pseudocereals quinoa (Chenopodium quinoa), kañawa (Ch. pallidicaule), potatoes (Solanum tuberosum), and barley (Hordeum vulgare). The Lake Titicaca region (Fig. 8.2), however, is more productive, supporting cultivations of maize (Zea mays), fava beans (Vicia faba), and a wider range of Andean tubers (such as Oxalis tuberosa, Ullucus tuberosus, and Tropaeolum tuberosum). Agriculture thrives in the Titicaca basin because it receives more moisture and has slightly warmer, more stable temperatures. On average, the lake area receives about 600–900 mm of rain annually (PROSUKO 1996; Roche, Bourges, and Mattos 1992:68). Figure 8.3 shows that two communities near the lake (Taraco and Pillapi) receive more monthly rainfall than the community about 20 km from the lake (Tiwanaku). Temperatures around the lake are still cold, averaging around 8ºC (Roche, Bourges, and Mattos 1992:66) (Fig. 8.3), but fluctuate less than the surrounding areas and experience fewer frosts. According to a study by
Two primary factors contribute to the more temperate microclimate of the Lake Titicaca basin. First, the lake is in the northern sector of the altiplano, which receives more precipitation than the south because of atmospheric circulation patterns (Lenters and Cook 1997). Second, the large body of water (approximately 8562 km²) absorbs a great deal of solar radiation and is warmer (10–14°C) than the surrounding air temperature (Wirrmann 1992:18). “The lake is therefore continuously giving out heat to its surroundings” (Roche, Bourges, and Mattos 1992:70). This radiation of warmth generates “thermal effects” (Boulange and Aquize 1981) producing more rainfall, warmer mean temperatures, and fewer frosts. This makes the Titicaca basin more agriculturally productive than the surrounding altiplano.

Although the lake environment provides better conditions for farming than the wider altiplano, farmers here still face several risks that can destroy their crops. While frost, hail, and pests are risks, the greatest limiting factor for production is rainfall. Unlike other regions of the Andes (Guillet 1987; Netherly 1984; Williams 2006), Titicaca farmers do not utilize irrigation systems to water their fields. Instead they depend entirely on yearly
rainfall, which is limited to three or four months a year. The quantity of rainfall received in this small window of time can make or break the yearly harvest.

**Dynamics of Rainfall and Lake Level**

The Andean region has one rainy and one dry season. The altiplano, in particular, receives most (70–90%) of its rainfall in the austral summer and is dry in the austral winter. The most precipitation occurs between December and February (Roche, Bourges, and Mattos 1992:71–72) (see Fig. 8.3).

While the large body of water influences local climate, the seasonal pattern of rainfall also influences the amount of water present in Lake Titicaca. The lake is approximately 8562 km² and consists of two basins (Fig. 8.2). The larger (7132 km²) northern basin is called Lago Chucuito. The smaller (1470 km²) southern basin is called Lago Wiñaymarka (Wirrmann 1992:19–21). The two basins are connected by the Strait of Tiquina, which has a sill about 20 m below the modern lake level at 3788 masl (Abbott et al. 1997:170; Wirrmann 1992:18). The mean modern lake level is considered to be 3810 masl. The lakes drain into the Lago Poopó basin to the south via the Desaguadero River. The sill of this outlet is about 5 m below the modern lake level at 3804 masl (Wirrmann 1992:21).

The lake level is dependent upon the balance of water input and output via various sources. The primary input sources are runoff and rainfall. Rivers from the eastern and western mountain ranges drain into the lake and account for about 53% of yearly input. Rainfall accounts for 47% of the yearly input (Roche, Bourges, and Mattos 1992:82–83). Although runoff is slightly greater, rainfall is more variable and thus has a greater influence on total yearly input.

The lake loses water by outflow and evaporation. When the lake is higher than the Desaguadero River sill (>3800 m), water drains out to the south. Outflow, however, only accounts for 9% of annual water loss while evaporation accounts for 91% (Roche, Bourges, and Mattos 1992:82–83). Given these variables, the balance between precipitation and evaporation largely determines the lake level (Abbott et al. 1997:170; Baker et al. 2001:642; Roche, Bourges, and Mattos 1992:65, 81).

Seasonal fluctuation in rainfall causes the lake to rise and fall during the year. The lake rises to its highest point at the end of the rainy season and after the peak of river runoff, usually in April. Evaporation occurs
throughout the remaining eight months of sunny, dry weather and the lake drops, usually reaching its lowest point in December (Roche, Bourges, and Mattos 1992:79). Based on modern records, the lake shifts approximately 0.7 m annually (Cross et al. 2001:3).

While this change may not be as noticeable in Lake Chucuito, such a shift is very obvious in the shallow Lake Wiñaymarka, where I conducted my research. The two photographs in Figure 8.4 show the same point in the community of San José in January 2004 and April 2004. The exposed land where fava beans grew in January was inundated by April. In the area I worked, a strip of land approximately 10 m wide is covered and exposed during these seasonal shifts. As I will describe below, this dynamic plays an important role in agricultural land-use strategies of farmers living near the lakeshore.

In addition to the seasonal fluctuation of rainfall, there is also interannual variation. Current research suggests that interannual variability of rainfall in the altiplano correlates strongly with the El Niño–Southern Oscillation (ENSO) phenomenon (Garreaud, Vuille, and Clement 2003; Lenters and Cook 1999; Ronchail 1995; Vuille 1999; Vuille, Bradley, and Keimig 2000) (see Roberts, this volume). During warm ENSO phases (El Niño periods), the altiplano is drier and during cool ENSO phases (La Niña periods), it is wetter.

These fluctuations in interannual rainfall affect the average height of the lake causing the lake to lose or gain water overall. Between 1914 and 1989, Roche et al. (1992:79, fig. 10) monitored the lake level near Puno and found a total interannual range of 6.37 m (Fig. 8.5). The lake reached its lowest absolute level in December 1943 when it was −3.72 m below the datum (3809.93 masl) and reached its highest absolute level in April 1986 when it was 2.56 m above the datum. Thus, in addition to the seasonal fluctuations, there may be more drastic shifts in the average shoreline depending on the overall rainfall for a given year.

This discussion demonstrates how the Lake Titicaca basin landscape is shaped by oscillations between wet and dry periods, and high and low lake levels on a seasonal and annual basis. As a consequence, these fluctuations in rainfall and lake level influence the manner in which people farm this region. As with other arid regions discussed in this volume, the amount of rainfall dictates whether or not the plants will have enough moisture to thrive. In the Lake Titicaca basin, the quantity of rainfall and shifting
8.4 (a) Top photo shows a growing fava bean field in January 2004 with Lake Titi-caca waters approaching. Note the mostly exposed dirt pile to the right. (b) Bottom photo shows the harvested fava bean field in April 2004 with waters covering most of the field. The dirt pile is completely surrounded by water.
lake level also dictate where farmers can cultivate. I now turn to the ethnographic information I collected on the Taraco Peninsula to describe how farmers take advantage of soil diversity to account for rainfall variability.

**FARMING THE TARACO PENINSULA, BOLIVIA**

The Taraco Peninsula is a relatively low-lying (maximum 3810–4100 m) mountain range of approximately 100 km$^2$ that extends west into the southern portion of Lake Wiñaymarka (Fig. 8.2). From October 2003–2004, I lived in and conducted ethnobotanical research on farming and plant use in four Aymara communities located on the peninsula: Chiripa (pop. 313), Coa Collu (pop. 596), San José (pop. 205), and Santa Rosa (pop. 132) (Fig. 8.6). The communities consist of families that own between 2 to 7 ha of land where they build their homes and farm. Current landholdings are based upon the redistribution of land to highland indigenous populations during Bolivia's 1953 Agricultural Reform (Benton 1999:88; Klein 2003:215). Today,
The Taraco Peninsula, Bolivia and the participating communities.
most households consist of extended families with grandparents, spouses, and grandchildren. Smaller households of only nuclear families (two to four people) are becoming more common as people move to the cities of El Alto and La Paz.

Families practice a mixture of subsistence farming, herding, and fishing. They consume most of their produce, but they also sell portions of it to earn money for purchased items such as cooking gas, vegetables, bread, rice, and other household necessities. A typical day consists of recovering fish from nets set in the lake, tending to animals (typically cows, sheep, and pigs), cooking, and completing seasonal agricultural tasks. During my year on the peninsula and in subsequent visits, I participated in and observed each of these activities. The focus of my research was on farming so I conducted more detailed investigation on these practices.

**Research Methods**

I lived with a family in San José, which was in walking distance or a short bus ride to the neighboring communities. I collected information on the agricultural cycle, plant and land use through participant observation and interviews. Participation in this project was voluntary and therefore my sampling was opportunistic; however, I made a concerted effort to interview people from a range of socioeconomic levels, women and men, young and old, wealthy and poor. The data presented here derive primarily from 74 semistructured interviews that asked participants to recount an average agricultural year, describing the crops that are cultivated and the activities carried out each season. I included questions related to land use, soil types, and field maintenance, particularly crop rotation and fallow. I also completed 17 more detailed interviews that focused on the landholdings and cultivation practices of individual families. For these interviews, my research assistant mapped fields of individual landholders with a Garmin Geographic Positioning System 12, while I interviewed the farmer about the “life history” of each field. I asked what crops had been planted over the past several years and how long the field had been or would be fallowed. In total, we recorded 226 fields. These data are the basis for the descriptions provided below.
Crops, Rotation, and Fallow

Modern-day farming on the Taraco Peninsula and the greater Andean region is a combination of practices deriving from the pre-Hispanic Andes, colonial Eurasia, and modern agronomic science. Farmers are constantly experimenting with new products, particularly crops, fertilizers, and pesticides, while also utilizing long-standing cultivation and land-use practices. The primary crops on the peninsula today are the Andean cultigens: potato (*Solanum tuberosum*), oca (*Oxalis tuberosa*), isañu (*Trapeolum tuberosum*), ullucu or papa lisa (*Ullucus tuberosa*), quinoa (*Chenopodium quinoa*), tarwi (*Lupinus mutabilis* Sweet), and maize (*Zea mays*). The Eurasian cultigens include: fava beans (*Vicia faba*), peas (*Pisum sativum* L.), barley (*Hordeum vulgare*), wheat (*Triticum* sp.), and oats (*Avena sativa* L.). They cultivate most of the barley, wheat, and oats to feed livestock while the remaining crops are for human consumption.

In a typical year, farmers dedicate each of their fields to one of the major crops based on a fairly standardized system of crop rotation and fallow (Table 8.2). The system that the Taraco farmers follow is very similar to those collected in other regions of the basin (Orlove and Godoy 1986:191–90, Appendix 1).

Fallow is an essential part of the rotation. Although it has been said that fields near the lake can be continuously cropped (Buechler 1969:181; Vacher, de Thuy, and Liberman 1992:517), most people fallow fields for at least 1 or 2 years, but sometime up to 10 years. The only people I found who did not fallow were those with holdings too small to leave fields out of cultivation.

The potato is always first in the cycle immediately following the fallow. According to the farmers, the potatoes need many nutrients to grow and the rested soil provides them. The fallow also reduces the number of pests in the soil that can damage the underground tuber (Orlove and Godoy 1986:184).

Fertilizer is always added to the planted potatoes. Sheep dung is the most common fertilizer used, but people now frequently employ some chemical products. Because of the altiplano’s relatively low vegetation cover, the soils are relatively low in nutrients needed for sustaining crops. Farmers throughout the region use animal fertilizer, traditionally camelid dung, to augment soil nutrients and fertility, especially for potato production (Winterhalder, Larsen, and Thompson 1974:96–97).

Oca (a tuber) usually follows the potatoes. Although oca will occupy
Table 8.2. Examples of crop rotation and fallow in the fields of two families on the Taraco Peninsula, Bolivia, based on interviews conducted in 2004. The number associated with “rest” is the years a field was in fallow.

<table>
<thead>
<tr>
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<th>2003</th>
<th>2004</th>
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<th>2006</th>
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<tr>
<td>1</td>
<td>rest 4</td>
<td>rest 5</td>
<td>potato</td>
<td>oca</td>
</tr>
<tr>
<td>2</td>
<td>rest 2</td>
<td>potato/ullucu</td>
<td>oca</td>
<td>fava bean</td>
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<tr>
<td>3</td>
<td>rest 2</td>
<td>fava bean/peas/maize</td>
<td>barley</td>
<td>rest</td>
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<tr>
<td>4</td>
<td>rest 4</td>
<td>potato/ullucu</td>
<td>oca</td>
<td>rest</td>
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<td>5</td>
<td>rest 3</td>
<td>rest 4</td>
<td>potato</td>
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<tr>
<td>6</td>
<td>barley</td>
<td>rest 1</td>
<td>rest 2</td>
<td>rest 3</td>
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<td>7</td>
<td>fava bean</td>
<td>barley</td>
<td>rest 1</td>
<td>rest 2</td>
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<tr>
<td>8</td>
<td>potato</td>
<td>potato/ullucu/fava bean/maize</td>
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<td>9</td>
<td>rest 6</td>
<td>rest 7</td>
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<td>10</td>
<td>maize</td>
<td>rest 1</td>
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<td>fava bean/maize</td>
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<td>rest 1</td>
<td>potato</td>
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<td>potato/barley</td>
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<td>barley</td>
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<td>fava bean</td>
<td>rest 1</td>
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<td>fava bean</td>
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<td>fava bean</td>
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<td>16</td>
<td>rest</td>
<td>maize</td>
<td>potato</td>
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most of the field, farmers often also include rows of isañu (also a tuber), peas, and even potatoes. Fertilizers are not used with the oca. The farmers commented that the soil still maintains a lot of nutrients after the potatoes and the oca do not need as many nutrients as the potatoes do.

Fava beans generally follow oca, but are often planted with other crops, especially maize and quinoa. Fava beans do not need fertilizer either, and most farmers recognize that the legume actually gives nutrients back to the
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soil. The final year of production is a grain, commonly one of the Eurasian crops such as barley, oats, or wheat. In some cases, people placed quinoa in this position.\(^1\) Others will grow two years of barley and then leave the field to rest ending the cycle.

With this system of rotation and fallow, a family will have at least one field with each crop and several fields in fallow. This provides a yearly harvest of a range of products and also serves to reduce the risk of total crop failure. Usually at least one of these crops will produce even if some are attacked by a malady such as hail, frost, worms, drought, or flood.

**Agricultural Calendar**

When asked to describe the yearly agricultural cycle, almost all respondents began by describing a series of plowings that must be completed before planting. These can begin as early as February, but they conduct them primarily in July, August, and September. Field preparation usually begins by turning over the earth with an ox-drawn plow to loosen the soil and pull up plants (Fig. 8.7). Today, it is also common to hire a tractor, particularly for fallowed fields that have a thick mat of grasses and bushes.

After the plow passes, people follow along breaking up dirt clods with wooden sticks and metal picks or shovels. The dirt clods often form around plant roots, especially those of the introduced chixi grass (*Pennisetum clandestinum* Chiov.). In breaking up the dirt clod, they remove the dry plants and place them in a pile. After they finish removing the dried plants, they burn them. This not only removes the unwanted weedy plants, but creates ash that they till back into the soil as a type of fertilizer. Farmers usually plow the soil two or three times before planting. The farmers explain that this process is necessary for making the earth soft for planting, to expose nutrients that are beneath the surface, and also to kill insects and weeds.

Planting is the next task and is accomplished between the months of September and November, when rainfall is sporadic and light. People follow a fairly systematic order based on the crop, but also on the type of soil and location of the field. I will explain these last two variables in the following section. In general, farmers begin planting in September with the crops that take longest to mature. These include fava beans, quinoa, and maize. In October and November, they plant the tubers. To plant, a man or other strong individual directs the ox-drawn plow to make furrows, and women follow
behind either placing the tuber seed in the furrow or broadcasting grains. The farmer draws the plow back through to cover the seeds.

From December to March, the plants grow watered by the summer rains. Along with the crops, wild plants flourish during this time and it is necessary to remove them from the fields. Usually farmers conduct a major weeding effort in January or February, when the non-crop plants are young and easy to remove (Fig. 8.8). With a small pick, farmers (usually the women) walk through the rows of growing crops and manually pick and pull up the weedy species. Occasionally they use the plow to loosen the weeds and improve the drainage furrows. They also attend to the tubers at this time, mounding up the dirt around the plant. They state that this helps the tubers grow. After this weeding, people usually do not enter the fields again until harvest time.

The harvest starts as early as January for some crops, but mostly occurs between March and April. Farmers usually harvest the tubers first, as they allow many of the grain crops to dry in the field. Row by row, they use small metal picks to dig up the tubers. They harvest the grains either by pulling up the whole plant (quinoa) or cutting the base with a sickle. They make piles of the harvested crops and spend the dry months, June through August, processing them to eat or to store. As this occurs, the time for preparing the field approaches again and a new agricultural cycle begins.

This description provides a general view of how seasonal rainfall shapes the timing of the agricultural cycle. The farmers plan each step in the process so that the seed is planted before the rains come and that they mature before the rains leave. Obviously, insufficient rain will leave the plants without the water they need to grow, so a season with little rainfall could ruin a crop. Conversely, abundant rainfall is especially damaging to tuber crops that will rot or not mature if there is too much water.

There have been studies in the Andes that found farmers have methods to predict wetter versus drier years. As mentioned above, drought years often correlated with El Niño events. Based on his own observations and review of the Andean ethnographic literature, Benjamin Orlove found that several central Andean communities observe the brightness and position of the Pleiades in June to predict these dry spells (Orlove, Chiang, and Cane 2000:68, 2002). If the farmers find the stars of the Pleiades to be dim and/or fewer in number, they predict that it will be a dry year and set tuber planting back several weeks. According to studies completed by two
8.7 Planting on the Taraco Peninsula with ox-drawn plow.

8.8 Weeding a fava bean field.
climatologists, John Chiang and Mark Cane, a warm phase ENSO causes greater high cloud cover. These clouds are barely visible to the naked eye, but would be enough to dim the Pleiades stars (Orlove, Chiang, and Cane 2000:69, 2002:432).

During my study, I did not meet anyone on the Taraco Peninsula who made such observations and predictions. It is possible that this practice exists since several of the examples Orlove et al. (2000:68) cite are in the Titicaca basin. Even if they did not use the Pleiades to predict the timing of the summer rainfall, I found that farmers paid close attention to general weather patterns and would set back planting of particular crops until enough rain was available. I did observe people rushing out to buy the yearly Farmer’s Almanac, available for only one Boliviano (about 0.14 USD) in the town market and on the streets of El Alto. They read the small booklet for predictions about the year’s weather patterns. I did not find, however, that this directly impacted their decisions about when to plant. Through my interviews and observations, however, I learned that farmers take additional steps to account for the potential variation in rainfall by utilizing different types of soils present on the landscape. This is the focus of my discussion here.

SOILS OF THE TARACO PENINSULA

Based on a geological map of the peninsula (IGM 1994), the Taraco peninsula consists of a range of different soils types (Fig. 8.9). A rocky Pliocene conglomerate called the Taraco Formation (Ttc) forms the peninsula’s mountain range. The shores, plains, and gentle slopes of the peninsula contain gravel, sand, silt, and clay created by deep Pleistocene lakes and modern erosional processes (Qfl & Qcf). Colluvial deposits (Qc) of boulders and gravel occur in small pockets in hilltop valleys. Finally, alluvial deposits (Qa) of pebbles, gravel, sand, silt, and clay form where rivers have dissected the landscape. Thus, from a geological perspective, there is a range of soil types on the peninsula from deep silty clay deposits near the shore to very rocky (cobbles) deposits in the hills.

The residents of the Taraco peninsula also recognize these distinct geological deposits. In the interviews, they described four common soil types on the peninsula: laq’a, k’ink’u, ch’alla, and q’ala laq’a/ch’ata. Harry Tschopik (1963:513) and Luperio Onofre Mamani (1997) recorded similar
Lake Titicaca

Legend
- \( Qa \): Alluvial deposit
- \( Qc \): Colluvial deposit
- \( Qcf \): Colluvial fluvial deposit
- \( Qf \): Fluvio-lacustrine deposit
- \( Ttc \): Taraco formation

8.9 Geological map of the Taraco Peninsula. (Based on IGM map 1994)
soil categories in other areas of the lake basin. Below I present each soil category provided by the Taraco farmers, along with the descriptions of their characteristics, distribution, and productive potential (Table 8.3).

The most desirable soil is *laq’a* in Aymara or *tierra* in Spanish. This can be directly translated as earth or the lay term soil in English. This tends to be silty clay that is moist and loose. These soils are distributed near the lakeshores but also in some patches on the hillsides. They are easy to till and rich in organics, thus preferred by most of the farmers. *K’ink’u* is clay. It is bright red or yellow in color and is also found near the lakeshores and eroding out of ravines. I received a mixture of responses regarding its cultivation potential. It is cultivated, but as clay, it can become very hard in dry conditions but very slick in wet conditions. Thus, it is only cultivatable with a moderate quantity of rainfall. *Ch’alla* is sandy soil and usually found on the hill slopes. While some complained about the high quantity of stones that can be found in this soil, many described it as relatively easy to till and as productive. It is especially good for tubers because it drains well. Finally, *q’ala laq’a*, also called *ch’ata*, is a rocky soil. It is found mostly on the eroded hilltops but can also grade into the *ch’alla* on the hillslopes. This is the least desirable area for agricultural production because the loose soil component is thin and the abundant stones make it difficult to till.

### Table 8.3. Soil Terms, Distribution, and Qualities Based on Interviews with Taraco Farmers

<table>
<thead>
<tr>
<th>AYMARA</th>
<th>SPANISH</th>
<th>ENGLISH</th>
<th>LOCATION</th>
<th>POSITIVE QUALITIES</th>
<th>NEGATIVE QUALITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laq’a</td>
<td>Tierra</td>
<td>Earth, soil</td>
<td>Milli/Slopes</td>
<td>Moist, easy to till</td>
<td>Poor with heavy rains</td>
</tr>
<tr>
<td>Chi’ara Laq’a</td>
<td>Tierra negra</td>
<td>Black soil</td>
<td>Milli</td>
<td>Moist, easy to till</td>
<td>Poor with heavy rains</td>
</tr>
<tr>
<td>K’ink’u</td>
<td>Arcilla</td>
<td>Clay</td>
<td>Patchy</td>
<td>Can be moist</td>
<td>Too hard or too soft</td>
</tr>
<tr>
<td>Ch’alla</td>
<td>Arena</td>
<td>Sand</td>
<td>Slopes</td>
<td>Well-drained, fertile</td>
<td>Poor in drought</td>
</tr>
<tr>
<td>Q’ala Laq’a/Ch’ata</td>
<td>Tierra pedregosa</td>
<td>Rocky</td>
<td>Hilltop</td>
<td>Well-drained</td>
<td>Difficult to till, uncultivable in drought</td>
</tr>
</tbody>
</table>
Altitudinal Distribution of Soils and Timing of Planting

While some of these soils types, such as the clays, are patchy across the landscape, the descriptions show that there is a general vertical distribution from the lakeshore to the hilltop: the laq’a and k’ink’u are most common along the lakeshore, ch’alla and laq’a on the slopes, and q’ala laq’a/ch’ata on the hilltops. The agricultural cycle interviews revealed that farmers usually begin planting the soils along the shoreline first and make their way upslope. The logic of this order is based on timing of the rains, water retention qualities of the soils, and seasonal fluctuations of the lake level.

The farmers told me that the first soils to be planted, usually in August, are those near the lakeshore. The farmers call this land milli, which according to the Diccionario Practico Aymara-Castellano Castellano-Aymara (De Lucca D. 1987:112) literally means “first potato.” The milli is the swath of land along the shore that is inundated by the lake during its high stand between the months of April and July. The lake begins to fall in July and eventually exposes tracts of land that are moist and fertile. These conditions permit planting before the rains begin in October. I was told that any crop could be planted in the milli, but the most common crops were potatoes, fava beans, and grains.

It is necessary to plant the milli early for the crop must be ready to harvest before the lake rises again in late February or March. This zone is particularly important in years with little rainfall, as the soil moisture is often sufficient to produce a crop. According to Vacher et al. (1992:516), these moist lakeshore soils do continue to be productive during droughts. The crop can be in peril, however, in very wet years, as the plants may not mature before the water rises (Buechler 1969:181).

The soils of the milli are thick and can support dense vegetation such as grasses and sedges. Near the shoreline, the rising lake clears this vegetation making the area easy to cultivate. In areas where there is little slope directly above the shoreline, the dense vegetation and thick soils are difficult to manipulate without a tractor. These areas are often left uncultivated and instead used for pasture.

The second fields to be planted are those on the slopes above the milli. While I commonly heard this area referred to as pampa (plain) or laderas (slopes), it did not have a specific designator such as milli. This is the largest area of cultivation and has a variety of soil types. The most common type, however, is ch’alla. These soils are not moistened by lake or groundwater;
therefore, farmers wait for the early rains in October and November to plant here. In a year of average rainfall, these fields will yield an excellent crop. These sandy soils drain well so even with abundant rainfall the crops here will succeed. Unfortunately, in a very dry year, the crops here will have difficulty.

The final fields to be cultivated are in the q’illa or hilltops. Many published maps, such as the IGM 1:50,000 map (IGM 1991), indicate that these areas are not cultivated, but this is not the case currently. Several farmers I interviewed had fields in these areas. People with access to these areas cultivate them if the weather conditions permit. Rocky and thin soils, q’ala laq’a or ch’ata, occur here and require plentiful rain to successfully produce. For this reason, they are the last to be planted, in December or January, when there appears to be sufficient rain. In dry years, they may not be planted at all. These areas, however, will be successful in the very wet years.

I found that most farmers had landholdings in all of the soil types. Some seem to have obtained long swaths of land during the agricultural reform, but some gain access to different soils through familial connections. Additionally, many families share plots with friends and neighbors. If people outside of the immediate family help prepare and plant a field, they are often given a few furrows to plant their own seed (Carter and Manani 1982:136). Through these informal exchanges, people get access to types of soils they may not own themselves. The politics of landholding certainly shapes the modern mosaic of land use on the Taraco Peninsula, and likely did so in the past. Access to different soil types, however, may have always been important to Taraco farmers and the manner in which this was regulated likely changed with shifts in population densities and political organization.

**Crops and Soil Types**

In some regions of the Andes, particular crops are associated with particular ecological zones (Brush 1977; Goland 1991; Hastorf 1993; Mayer 1979; Orlove 1977). For example, within the Mantaro Valley of Peru, farmers have fields in low elevation, warm valleys exclusively for maize, as well as fields in high elevation, cold hilltops exclusively for potatoes (Mayer 1979:12–13). This is not the case on the Taraco Peninsula. According to my interviews, people follow the crop rotation across the entire landscape. Of course, certain crops do better in certain soils; for example, the fava beans
I saw growing on the hilltop were quite short, while those growing in the milli were lush and tall.

The only potential crop-soil correlation I encountered was for the small, uncommon tuber, ullucu. Many people mentioned that it grows best in the rocky soils on the hilltops. One might also expect to find a particular distribution for maize, as it is susceptible to frosts and low temperatures in general. While people did not correlate maize with any particular soil type, they plant it in protected areas such as small valleys or hillsides. It is almost never planted in the open plain for these areas experience strong frosts.

The ability to plant all crops across various soils and elevations on the Taraco Peninsula is likely due to the relatively low relief of the peninsula and the moderate climatic conditions of the lake region. In other Andean regions, such as the Mantaro Valley, steep topography presents distinct climatic zones (warm valley bottoms versus cold mountain tops) within a day’s walk. Although there are altitudinal differences in soils on the peninsula, they only vary by a few hundred meters in elevation compared to thousands of meters in the central and coastal Andean valleys.

The elevation of the Taraco Peninsula (3800–4000 m) actually falls within the range of what is considered to be the cool, potato-growing regions of the Andes (Pulgar Vidal 1972; Troll 1968). As mentioned earlier, however, the thermal effects of the lake create moderate conditions similar to the lower Andean valleys where maize can be grown. Thus, the Taraco Peninsula is unique for the Andes in that a wide range of crops can be planted in a single area.

A MODEL FOR UNDERSTANDING RESPONSES TO LARGE MAGNITUDE CHANGES IN RAINFALL

This case study demonstrates how generations of farmers working on a particular landscape with particular risks develop knowledge and practices that enable them to minimize possible losses and shift their strategies if necessary. The practices detailed above show how Taraco farmers reduce the risk of crop failure due to unpredictable rainfall by taking advantage of soil diversity in their landscape. Each year, they plant a range of crops across each soil type. In addition to assuring that at least a few of their crops are successful, the recognition of how different soils behave in different conditions prepares people to shift practices if one type of rainfall pattern
(drought or flooding) begins to persist. I suggest that this ethnographic documentation of how farmers have adapted to short-term climatic fluctuations can provide insight into how farmers might respond to persistent periods of drought or flooding. Below, I present a hypothetical model of land use under longer-term dry and wet conditions. This could be used to predict how populations might react in the future to such conditions, but also serves as a model to be tested with archaeological data for understanding past responses to the documented climatic shifts mentioned at the beginning of the chapter (Table 8.1).

The lakeshore is much like a riverine floodplain, with the waters rising and falling on a seasonal basis creating moist, loose soils. Under persistent dry conditions or a long-term drought the lake level would drop (see Fig. 9.2 in Moore, this volume) and the population could follow the diminishing lake shore to take advantage of the remaining moist, cleared soils. In modern times, there are stories of farmers moving onto exposed lakebed after severe droughts in the 1860s and 1940s (Erickson 1999:637). The lands left behind by the lake would eventually become dry, grassy, and difficult to till. This area may lose its agricultural significance and become more important for pasture, as the flat pampas are used on the peninsula today.

During dry years, the slopes of the Taraco peninsula may continue to be cultivatable, as long as there is some yearly rainfall. Archaeologically, we know that there continued to be rather dense populations in this area even during documented dry periods (Bandy 2001:101; 2006:229). This suggests the slopes soils are still cultivatable during droughts. The hilltops, however, would probably become uncultivatable.

Under wetter conditions, the tendency of land use would reverse from that practiced under drier conditions. When the rains increase the lake will fill again. Any lands that were in the lakebed would be lost and the higher areas would become more important. With the loss of potential agricultural lands in the lake bottom, the hilltop may provide needed terrain. Additionally, the well-drained soils of the slopes and hilltops would be more productive in seasons with greater precipitation than the clay-rich, flood-prone soils in the lower elevations.

In the past, the use of raised fields may have also been a solution to recovering lands lost to higher lake levels. Archaeologists have documented approximately 82,000 km$^2$ of ancient raised fields throughout the Lake Titicaca basin (Smith, Denevan, and Hamilton 1968:355). While most of them
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appear to date to the Tiwanaku period (Janusek and Kolata 2004; Kolata and Ortloff 1996; Stanish 1994), there is evidence that they first appeared in the Formative period (Erickson 1988; Stanish 1994). Although the focus of raised field research has been on their potentially superior productive capabilities (Erickson 1996; Kolata 1991), they also provide an important technology for making the inundated lakeshore productive.

This hypothetical model is a very general scheme that only accounts for climate and land use. In order to determine the actual dynamics of a response to large magnitude climate changes, we would also have to take into account other economic activities such as herding and fishing as well as the social and political entities that regulate access to land and the coordination of agricultural activities. As several of the chapters in this volume point out, the ability to successfully respond to climate change may have more to do with social and political responses than economic decisions or adaptations. My goal in presenting this land-use model based on ethnographic data is to provide researchers a baseline with which to add more data sets. More complex models of behavior could be used for future planning in the face of climate change, but also to better understand responses to past climate change.

CONCLUSIONS

In this paper, I have discussed how farmers on the Taraco Peninsula, Bolivia, have used soil diversity on the landscape to deal with the risk of variable rainfall. Farmers plan the yearly planting schedule around the timing of summer rains and distribute their fields across different soil types with distinct water retention/drainage properties. Dispersal of fields in all soil types and a staggered planting schedule ensure farmers of at least a few successful crops regardless of abundant or scarce rainfall. This case demonstrates how farmers, confronted with annual climatic uncertainty, develop regular practices that account for these irregularities. In fact, such practices may prepare them to successfully respond to longer-term shifts in rainfall patterns thus reducing the possibility of catastrophic failure of the farming system. This type of flexible land use and inclusion of other complementary economic activities such as herding and fishing may explain why the Taraco Peninsula, and the greater Titicaca basin, has successfully sustained farmers for over 2,000 years.
Acknowledgments

I am very grateful to the people of the four communities—Chiripa, Coa Collu, San José, and Santa Rosa—that participated in my project and kindly shared their knowledge of farming the Taraco Peninsula. Permission to conduct the ethnobotanical research was granted by the Herbario Nacional de Bolivia and the Dirección General de Biodiversidad. IIE Fulbright, the Wenner-Gren Foundation (Small Grant #7073), and the National Science Foundation (Dissertation Improvement Grant #0321720) provided funds for this research. I wish to thank Eduardo Machicado for his help with the data collection and creation of the maps presented here. He also provided useful advice in the revision process. I thank the organizers of the Forces of Nature conference for inviting me to contribute and thank the other participants for their useful feedback. I am especially grateful to Katherine Moore for her feedback in revisions of this paper, as well as her close collaboration over the years.

NOTE
1. It is worth mentioning that it seems fava beans have nearly replaced quinoa as a major crop on the peninsula. Based on studies of rotations in other parts of the altiplano, quinoa usually was the third year crop. I only met a few families who dedicated entire fields to quinoa and if they had, the next year they would not plant it again. From my questioning, I gathered that quinoa is not as important a food anymore. Instead people eat more fava beans, rice, pasta, and bread. Also, fava beans are a cash crop that is sold to vendors in the La Paz and the Peruvian cities across the lake. Thus, for a variety of reasons, quinoa and its relatives are no longer an important part of the Taraco landscape, although it was prehistorically (Bruno and Whitehead 2003; Wright, Hastorf, and Lennstrom 2003:387).

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