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Climate and settlement in Southern Peru: the Northern Río Grande de Nasca drainage between 1500 BCE and 1532 CE

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4 Culture Meets Nature

In any context, the natural environment and human cultural development are closely interrelated. Human societies often heavily modify the landscape, and environmental parameters fundamentally influence human subsistence, movement, and behavior. This relationship is the research field of cultural ecology, which is to a large degree rooted in the pioneering works of Julian Steward (1938). By now, it also includes several new theoretical and methodological branches developed during the last 80 years (Bargatzky 1986, Ellen 1982, Sutton & Anderson 2010). For the reconstruction of non-literate past societies the theoretical concepts of cultural ecology are of great value (Butzer 1982) although interpretation exclusively based on material remains is necessarily much less accurate than the description of a living community based on the real-time observation of behavior and the interrogation of informants. In this chapter some general theoretic considerations about the dependence of societies on natural resources will be presented before turning on to the specific case of the Central Andes, and in particular, of the study area.

4.1 The Impact of Resource Availability on Culture

Aside from providing a great variety of resources, nature also has a strong influence on religion and world view (contributors in Gottlieb 2010 and Taylor 2008). Some religious practices constitute spiritual means of insuring the availability of crucial resources. In the Andes, for example, the worship of mountain peaks is often linked to a water and fertility cult (Glowacki & Malpass 2003, Reinhard 2002). The importance of water, in turn, stems from the need to produce food, e.g., by rain-dependent agriculture or irrigation farming.

The relation between natural resources and culture is therefore basically economic in character and can be explained in terms of supply and demand (Tainter 1988). Nature *supplies* a variety of resources potentially exploitable by humans. People, in turn, *demand* certain material goods. This includes the most obvious needs for food, water, clothing, housing, and essential tools along with culturally desirable goods such as luxuries and ceremonial objects. People can meet their demand by exploiting the natural resources of the environment they live in, or by obtaining goods from distant areas by peaceful trade or by using force to raid or to extort tributes. Some environments offer a few resources in great abundance while others are lacking completely. A group inhabiting such an environment may choose to specialize on what is readily available. The generated surplus can then be exchanged with societies that have access to goods unavailable locally.

Which resources are considered worth exploiting, how they are exploited, and at what scale, all depend upon culture. Only some of the totality of potentially available resources will actually be used. For example, not everything edible and nutritious is accepted by everybody as food and there is often a distinction between low status and high status food.[62] Some goods are highly valued because they play an important role in rituals. In pre-Hispanic times, the warm water Spondylus oyster (*Spondylus princeps*) was traded over large distances from the coasts of Ecuador all over the Andes, because it was a religious symbol linked to fertility cults (Carter 2011, Murra 1975b). With the introduction of Christianity by the Spaniards, the demand for Spondylus collapsed completely. Luxuries are even more subject to particular traditions and also to temporal fashions. They may be of great value for a certain cultural group but regarded as cheap and ordinary by another, e.g., glass pearls offered by European merchants to native tribal societies in North America (Dubin 1997:271–274).

If *per capita* consumption remained stable, then the amount of required resources and hence the scale of exploitation would simply be pro-

[62] Cf. Fox n.d., especially Chapter 2. Mintz et al. (2002) give an overview about recent literature on the cultural aspects of food consumption.

portional to population size. This may not be the case, however, when goods can be acquired more easily due to new technologies and strategies, because the surplus might not only be used to maintain more people but also to increase per capita consumption. In many societies, not only the access to prestige goods but also the consumed and redistributed quantity of every-day goods defines the social status of an individual (e.g., the potlatch feasts practiced by northwestern American tribes, Beck 1993). This may lead to extensive wasting in order to gain prestige. Since the measure of returning to a more rational use of resources in times of scarcity will be perceived as a loss of living standard and social status, it will be avoided as long as possible. On the other hand, the resources which nature has to offer are not stable either. Mines may eventually be depleted, soils exhausted, forests clear cut, game and fish populations over-hunted and over-fished. All of these scenarios would be direct consequences of unsustainable human exploitation. Some of these effects are reversible, others are not.

There are two further important factors outside the ambit of human control: climate and geology.[63] Although events such as earthquakes and volcanic eruptions may cause heavy destruction and loss of life, they only constitute single events, limited to a certain region. While this is also true for occasional storms, floods, torrential rains, short-term droughts, and unexpected frosts, long-term changes in climatic conditions have much further-reaching consequences (cf. Clare & Weninger 2010). Climate affects all organic resources (whether produced or foraged) directly and indirectly by determining the amount and distribution of precipitation, the length of growth periods, the limits of habitats, and so on. Rates of wind and water erosion may also fluctuate. While mineral deposits can only diminish, resources like arable land, forests, water, game, etc. can also recover or increase under especially favorable climatic and environmental conditions or by human landscape engineering.

Given the volatility of demand for and supply of resources, no stable equilibrium can be expected on the long run. While a growing resource base offers the possibility of population growth and increased *per capita* consumption to human groups, shrinking resources can cause serious problems to societies that are already exploiting them to maximum. Possible lines of solutions to such challenges are:

1) *Accessing new sources.* This is applicable to all resources that are not rare or localized (as are certain minerals and ores). New sources can be accessed by widening the catchment area, by using marginal, less productive sources, or by migrating into still un- or under-exploited regions. A widening of the catchment area can be reached by splitting groups into smaller dispersed units (satellites), by increasing the time investment for the exploitation of distant resources, or by increased movement speed, e.g., by the construction of roads and bridges, or the use of mounts (horses, camels, elephants).
2) *Increasing productivity via new technologies or strategies (intensification).* This is predominantly applicable to organic resources (hunting, farming, herding, foraging). For example, yields per hectare can be raised by means of using fertilizer, breeding and growing more productive crops, or employing irrigation. Increasing productivity can be sustainable or not. In the first case, the quantity of resources remains stable or grows, while in the second, the raise in productivity is reached by depleting the reproductive base, resulting in short term surplus but long-term resource exhaustion. Classical examples would be over-hunting and over-fishing, and clear-cutting of forests.
3) *Substituting or diversifying resources.* This is applicable to most types of resources. For example, people living close to the shore can replace agricultural products – at least partly – by fish and other seafood and vice versa. Tools normally made of metal can be made of stone, wood, or bone instead; hides can replace textiles, and so on. Substitution, however, in most cases means a loss of productivity and functionality, or at least of social status and prestige in the framework of certain cultural values.
4) *Reducing per capita consumption.* This is particularly applicable to all resources necessary to provide non-vital goods such as luxuries. A reduction of investment in communal social institutions (political-administrative and religious) also decreases resource use. Societies with a high degree of non-vital consumption thus have the biggest potential for retrench-

[63] The present-day influence of human activities on world climate only takes effect because of the large number of people (seven billion), the massive burning of fossil fuels, and large scale deforestation. All of these phenomena are limited to the last two centuries of human history. On a local and regional scale, however, deforestation may also have affected climate in the past.

ment. A decrease in *per capita* consumption of food is limited by the minimum number of calories needed for human survival.

5) *Permanently reducing demand via population control.* This measure decreases the need for all kinds of resources and can be achieved by migration, birth control, or, in extreme cases, by starving to death or physically exterminating competing groups by means of war.

When available resources no longer suffice, one or several of these five strategies will have to be pursued. Even if a society did not respond to the situation, this would simply mean that its members would starve to death and this would be their unintended "solution". Obviously, not all options are available to all groups of people in all environments and situations. If possible, options 1) and 2) will probably be the first choices while options 3) to 5) should be regarded as emergency measures.

When archaeologists and historians find evidence that a past society had to reduce consumption to a great extent and suffered heavy population losses, they generally speak of crisis, decline, or collapse. The literature on the topic is abundant, but two recent articles, one by Guy Middleton (2012) and another by Joseph Tainter (2006), offer detailed reviews and discussions of different perspectives and interpretations of the phenomenon.[64]

Two highly influential works especially have fueled recent debates about cultural responses to situations of long-term resource shortages: Joseph Tainter's *The Collapse of Complex Societies* (1988) and Jared Diamond's *Collapse: How Societies Choose to Fail or Succeed* (2005). Both authors analyze case studies of past societies that faced such crises. Diamond's general reasoning can be summarized as follows: When population – and therefore the demand for goods – increases, resources become scarce, no new resources are available, and migration is not possible, then people have two basic options:

- They can take measures to reduce *per capita* consumption or the number of consumers or they can substitute or diversify resources early on.
- They can consume the reproductive base of potentially renewable resources in an unsustainable way. In the long run, this will inevitably lead to collapse ("ecocide").

Diamond's book, however, is of popular character. It depicts scenarios of what its author considers likely to have happened in the past, but it does not present a thorough theoretical framework.[65]

In contrast, Tainter developed a detailed and sophisticated theory about economic factors underlying major breaks in cultural development. Tainter defines *collapse* as:

> [...] a political process. It may, and often does, have consequences in such areas as economics, art, and literature, but it is fundamentally a matter of the sociopolitical sphere. A society has collapsed when it displays a rapid, significant loss of an established level of sociopolitical complexity. The term 'established level' is important. To qualify as an instance of collapse a society must have been at, or developing toward, a level of complexity for more than one or two generations. [...] The collapse, in turn, must be rapid – taking no more than a few decades – and must entail a substantial loss of sociopolitical structure. Losses that are less severe, or take longer to occur, are to be considered cases of weakness and decline (1988:4).

Accordingly, the level of complexity is crucial. For Tainter, complexity refers to "such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functional whole. Augmenting any of these dimensions increases the complexity of a society" (1988:23).

Later on, he lists constituents of complexity which include "agriculture and resource production, information processing, sociopolitical

[64] Also see Tainter (1988) for an exhaustive discussion of numerous works and approaches published before 1988.

[65] Much of Diamond's work has been rejected by scholars specialized either in the cultures he used as case studies (contributors in McAnany & Yoffee 2010) or in the phenomenon of collapse itself (Middleton 2012, Tainter 2006), principally for two reasons: 1) In some of his cases, the archaeological record in fact does not argue for an unambiguous scenario of catastrophic collapse after Diamond's own definition but for long-term cultural adaption or migration. Diamond just ignores facts that do not fit into his model. 2) The images he draws of his case-study societies are often too coarse-brushed, one-sided, and lack profound understanding of the particular cultures. Diamond's apparently poorly researched popular article in The New Yorker about tribal warfare in Papua New Guinea further fuels this critique (Balter 2009).

control and specialization, and overall economic productivity" (pp. 93–94). In this sense, scale and sophistication of production and extraction contribute to the overall complexity as does the degree of administration, organized religion, military organization, and social stratification. From here on, I will draw on Tainter's definitions when using the terms *collapse* and *complexity*.

Tainter emphasizes that societies are generally problem solving organizations: if a society fails to respond to stresses because it chooses to take no or inadequate measures, then it has to be asked which were the cultural factors that hindered finding a solution. In other words, a single event as well as a process of worsening environmental or social and political parameters can only trigger a collapse when cultural factors prevent a society from successfully dealing with the challenge.

Tainter bases his model on economic theories about productivity, outlined by Hadar (1966) and Hailstones and Mastrianna (1988), which focus on average and marginal products, where "[t]he average product of an economic activity is simply the output per unit of input. The marginal product of any input is the increase in the total output resulting from the input. Similarly, the average cost is the cost per unit of input, while the marginal cost is the increase or decrease in total cost resulting from one more (or less) unit of input" (Tainter 1988:92).

Later on, he replaces the term "product" with the more general "return" which is not limited to the production of goods but refers to all kinds of benefits including security and welfare. He argues that while complexity is still low and resources readily available an increase in a society's investment (time, labor, money, etc.) in complexity leads to an increased average return. After a while, however, the rate of increase in productivity – the marginal return – goes down and may eventually turn negative. At a certain point, any further investment in complexity will actually *decrease* the average return. From then on, a society's resilience starts shrinking, making it more vulnerable to any kind of stress.

Finally, a catastrophic event that would previously have been dealt with effectively can trigger a collapse. If this happens, it is not the severity of the event itself which prevented a successful handling of the crisis but the instability of the affected society. Worsening environmental factors as well may operate as an ultimate trigger for the collapse of a society, but its deeper causes nevertheless lie in the culture, namely in the level of complexity. As collapse means a drastic reduction of complexity (and often also of population), it also implies that *thereafter* marginal returns are likely to rise again. Provoking collapse, e. g., by revolting against ruling elites, may therefore even be a conscious strategy of some segments of a society to reestablish a favorable cost-benefit relation for the maintenance of a certain level of complexity (Tainter 1988:118–123).

In in the present study it will also be asked, whether or not there are any signs indicating a collapse in the regarded 3000-year cultural sequence and, if the answer is yes, if, speaking with Diamond, people failed to make the right choices when facing environmental problems or if, as Tainter might argue, collapse was just the better alternative to further increasing complexity at too high a cost. After these general considerations, the specific situation of man-environmental relationship in the Central Andes and especially the study area in the Northern Río Grande de Nasca drainage shall be addressed.

4.2 Particularities of Human-Environmental Relationships in the Central Andes

Economic human-environmental relationships in the Andes are a vast topic which cannot be treated in detail in the scope of the present study. A recent overview of theories concerning the economies of pre-Hispanic societies in Peru is given by Peter Kaulicke (2008:151–196).[66] Before continuing forward, two peculiarities of the Central Andean environment should be considered which are especially crucial for understanding the interaction between nature and culture in this unique landscape setting.

Firstly, maritime resources along the coast are extraordinarily abundant and provide a highly productive food source, especially at some "hot spots" such as the Paracas peninsula. In 1975 Michael Moseley published his well-known study *The Maritime Foundations of Andean Civilization* in which he argues that the earliest complex societies on the Peruvian coast based their subsistence economy predominantly on seafood while farming was marginal and largely limited to the industrial crops cotton and gourd, used to fabricate fishing nets and floaters. At the Peru-

[66] Kaulicke's chapter is about the economy during the Formative (Initial Period and Early Horizon), but he also discusses some much more general approaches not bound to a specific region or time section.

vian coast, maritime resources alone sufficed to support large and permanent early settlements while the cultivation of staple crops was a later development. Moseley's thesis had been challenged by other authors but recent studies seem to reconfirm it (Sandweiss 2009). Although irrigation farming became dominant in food acquisition for most coastal societies since the Initial Period, fishing remained important throughout history, including modern times.

The second peculiarity is the unique diversity of environments, each with its particular resources, within a very short distance.[67] The desertic Pacific coast and the Amazonian rain forest are separated by only 250–500 km, and in between sit the Andean mountains, presenting almost all possible altitudinal steps. This landscape enables people to diversify their economy by directly making use of the potentials of several different environments or by exchanging goods with nearby neighbors who nevertheless have access to a completely different set of resources. This also minimizes the risk of famine due to crop failures in a given environment because the loss can be compensated to a certain degree by the unaffected harvests in another region. Accordingly, the organization and often institutionalization of exchange systems has been crucial for arguably all sedentary Andean societies, though we have more detailed information only for some groups of the last centuries before the Spanish Conquest and of later times.

In 1972, John Murra published his influencial study *El control vertical de un máximo de pisos ecológicos en la economía de las sociedades andinas* (Murra 1975a, also see Murra 1985a). Based on early colonial documents, in this essay he presents five cases of late pre-Hispanic ethnic groups of different size and complexity from the highlands and from the coast. Each of these groups possessed permanent colonies in different ecological niches far away from its respective core territory. The colonists did not lose ties with their home communities but formed part of their extended and diversified economic systems. It is not clear, however, to what degree the same concept may have applied to societies in the more distant past (Murra 1985b).

Murra's study triggered broad ethnohistorical and archaeological research on the topic of complementarity all over the Central Andes. As a result, numerous variants of the vertical control model were described or proposed for different regions and societies (e.g., Farrington 1984, contributors in Masuda et al. 1985). For the Southern Highlands and the Extreme South Coast, Núñez and Dillehay (1995) developed a model for earlier pre-Hispanic epochs based on a network of principal market settlements ("asentamientos-ejes") connected by regularly operating llama caravans which could transport goods over considerable distances. In several aspects, they draw on approaches originally developed by David Browman (1984/2008) who stressed the importance of camelids in the long-distance exchange system.

Jürgen Golte (2001) described the strategy of cultivating fields at different altitudes successively, as each environment has its own agrarian cycle. In this case, each family may possess fields in several ecozones and temporarily moves close to those that need to be cultivated or harvested during a specific season. In her study of the Lupaqa ethnic group in the western Titicaca region, Mary van Buren demonstrated that the vertical archipelago strategy actually served to supply social elites with high-status goods usable in political negotiations, etc., rather than complementing the daily diet of commoners. She argues that "barter and exchange, perhaps between people who were ethnically distinct, may have been a more important element in prehistoric household subsistence practices than is currently acknowledged" (1996:348).

Whatever the precise strategies – (semi-)nomadism, colonization, interethnic trade/exchange, or a combination of these – it is reasonable to assume that the acquisition of a wide range of products from different ecozones had always been desirable to all inhabitants of the Central Andes. For this reason, no society can be fully understood if seen only in the environmental context of its immediate core territory. The resources that were available nearby will nevertheless have been especially important. In the case of farming societies inhabiting the study area between 1500 BCE–1532 CE this particularly concerns arable land and water for the cultivation of *yunga* and *quechua* crops. In some phases the grasslands of the *puna*, which served as pasture for camelids, were also essential.

4.3 Past Climate and Its Impact on the Agricultural Potential

As outlined in the Chapter 2.1, the pre-Hispanic inhabitants of the Río Grande drainage poten-

[67] 84 out of 103 of the Earth's life zones after the Holdridge-Tosi classification system can be found within the borders of present-day Peru (INRENA 1994).

tially had access to a great variety of natural resources, either directly or indirectly via trade and exchange. The supply, however, may have varied through time due to source depletion, disruption of trade routes, and a diminished agricultural potential. Since the Initial Period, agricultural products undoubtedly made up the biggest part of the diet, though hunting, fishing, and herding was also important.

The most important climatic factors for agricultural production are precipitation and – at high altitudes – temperatures during the growing season. Ideally, precipitation is not only sufficient on aggregate but also well distributed over the course of the growing season, and temperatures do never fall below 0°C. Deviations from this ideal situation can be compensated to a certain degree, for example by storing water in reservoirs, by breeding especially frost tolerant crops, or just by producing and storing a significant surplus in good years which can be consumed in cases of crop failures. If unexpectedly strong, frequent, or prolonged deviations from the norm occur, farming societies may not have enough time to adapt and may slip into a serious crisis causing population decline and the dissolution or drastic change of social order and political and religious institutions.

Accordingly, the impact of climate change on agriculture needs to be examined in some detail. Recent studies in South Columbia have shown that ecozones frequently shifted by several hundred altitudinal meters throughout the Holocene, sometimes within a single century (González-Carranza et al. 2012). Though the climatic regime in South Peru is different, the frequency and amplitude of such shifts, including those of the limits of agriculture, may have been at least similar. Due to the extreme aridity and the resulting sensitivity to changes in absolute values, especially with reference to precipitation, ecozone shifts may have been even more pronounced. The possible amplitude of change of the principal climate factors and the resulting impact on ecozone borders as well as on the extent of agriculturally usable land shall be discussed in the following.

4.3.1 Precipitation

Precipitation patterns are a highly complex matter and depend on many locally diverse factors, particularly air movements, latitude, cloud cover, altitude, topography, and so on (c.f. Barry 1992). Accordingly, "it seems unwise to quote regional altitudinal moisture trends as 'altitude phenomena', as such gradients could also be studied in non-mountain regions. Specific regional moisture gradients are best addressed as such, although they might locally be following an altitudinal gradient" (Körner 2007:572).

In the study area and on most of the Central Andean west flank, such an altitudinal gradient is indeed observable. Due to the fact that no reliable long-term measurements of precipitation along a transect from sea level up to the highest peaks are available, it cannot be said if the relation between precipitation and altitude can be expressed by a general mathematical function, e.g., a linear or an exponential one. Any precipitation values for altitudes between those at which the few meteorological stations are located have to be interpolated and can thus only be regarded as very rough estimations.

Judging from observations on vegetation development (Mächtle 2007), the precipitation increase with altitude seems to be best described by an exponential function, at least between about 2000 and 4000 m.a.s.l. The actual (unknown) course of the graph, however, may deviate from that of an exponential function. It may be much steeper for lower altitudes and may flatten at higher elevations. In those zones, a linear model might apply better, though this is purely hypothetical. For a comparison, annual precipitation amounts will be interpolated according to both, a linear and an exponential model, none of which should be misunderstood as fact data based on measurements.

The increase of precipitation per altitudinal meter (precipitation gradient) can be calculated if both variables (altitude and precipitation) are known for at least two places at different heights. After Mächtle and Eitel, the isohyet of 200 mm accumulated annual rainfall marking the desert margin under today's hyper-arid conditions runs roughly along the 2000 m isohypse, which may serve as the first reference (Mächtle & Eitel 2013:Fig. 1). In addition to the desert margin, a second date should be taken from a distant highland site to cover the entire altitudinal span. There is, however, no local long-term precipitation data available for the *puna* ecozone. The closest stations at which such data has been recorded are Pacococha (4356 m.a.s.l.) and Accnococha (4520 m.a.s.l.) in the headwaters of the Pisco and San Juan (Chincha) rivers.[68] During the observation period from 1942–1950, the average accumulated annual precipitation at Pacococha was 992 mm while at Accnococha the

[68] See folder "ClimateData" on the supplement DVD.

Borders between Ecozones	Precipitation (exponential model)	Precipitation (linear model)	Altitude under hyper-arid conditions	Estimated altitude under different conditions			
				hyper-arid to arid	arid	arid to semi-arid	semi-arid
desert margin	*200 mm*	*200 mm*	*2000 m.a.s.l.*	*1625 m.a.s.l.*	*1250 m.a.s.l.*	*875 m.a.s.l.*	*500 m.a.s.l.*
Lower limit for risky rain-fed farming	*241 mm*	*285 mm*	*2300 m.a.s.l.*	*1925 m.a.s.l.*	*1550 m.a.s.l.*	*1125 m.a.s.l.*	*800 m.a.s.l.*
lower limit for reliable rain-fed farming	*371 mm*	*483 mm*	*3000 m.a.s.l.*	*2625 m.a.s.l.*	*2250 m.a.s.l.*	*1875 m.a.s.l.*	*1500 m.a.s.l.*
chala-yunga	79 mm	0 mm	500 m.a.s.l.	125 m.a.s.l.	–	–	–
yunga-quechua	241 mm	285 mm	2300 m.a.s.l.	1925 m.a.s.l.	1550 m.a.s.l.	1175 m.a.s.l.	800 m.a.s.l.
quechua-suni	505 mm	625 mm	3500 m.a.s.l.	3125 m.a.s.l.	2750 m.a.s.l.	2375 m.a.s.l.	2000 m.a.s.l.
suni-puna	687 mm	767 mm	4000 m.a.s.l.	3625 m.a.s.l.	3250 m.a.s.l.	2875 m.a.s.l.	2500 m.a.s.l.

Tab. 1. Assumed relation between accumulated annual precipitation and altitude under hyper-arid (present-day), arid, and semi-arid (14^{th} century CE) conditions. Table: VS.

corresponding value for the period 1948–1978 is 756 mm. The mean would be 874 mm. Accordingly, altitudes at 4400 m.a.s.l. should receive about 880 mm. Given the relative proximity, a similar value can be assumed for the *puna* above the Río Grande drainage.

In a linear model, absolute values can now be calculated as follows: As the altitudinal difference between 2000 m.a.s.l. (desert margin) and 4400 m.a.s.l. is 2400 m and the difference in accumulated precipitation amounts to 880 mm - 200 mm = 680 mm, precipitation should increase by 680 mm/2400 m = 0.28333 mm/m ≈ 0.28 mm/m. All data used in this calculation is estimated and the resulting value should not be considered an exact constant. Based on this calculation, the border between yunga and quechua, which runs at 2300 m.a.s.l. and thus 300 m above the desert margin should receive 300 m × 680 mm/2400 m = 85 mm more than the 200 mm of the desert margin, say 285 mm. This border also tentatively marks the lower limit of rain-dependent farming if special techniques for optimal water storage are applied. Cultivation will be risky, however, because in years with below-average precipitation, crop failures will be severe. Reliable large-scale rain-fed farming becomes possible above approximately 2700–3000 m.a.s.l., depending on local microclimate, where annual rainfall should accumulate to more than 350 mm. Precipitation at the quechua-suni border at 3500 m.a.sl. would accumulate to 200 mm + (1500 m × 680 mm/2400 m) = 625 mm, and at the transition between suni and puna at 4000 m.a.s.l. the calculation would result in 200 m + (2000 m × 680 mm/2400 m) = 767 mm (Tab. 1).

For an exponential model, the growth factor F has to be calculated in a similar way as the interest rate is determined in financial calculations, though in this case the intervals do not refer to time but to altitude and the factor is not given in percent.[69] Intervals of 50 altitudinal meters should be appropriate, which means that the number of intervals n_F between the two reference points at 2000 and 4400 m.a.s.l., respectively, is (4400–2000)/50 = 48. If P_{4400} is the annual precipitation at 4400 m.a.s.l. (880 mm) and P_{2000} is the annual precipitation at 2000 m.a.s.l. (200 mm) then:

$$F = \sqrt[n_F]{P_{4400} / P_{2000}} = \sqrt[48]{880\text{ mm}/200\text{ mm}} \approx 1.03135$$

Now it is possible to calculate the precipitation P_x at any altitude x (rounded to 50 m), where the number of intervals is $n_x = (4400-x)/50$, with the formula:

$$P_x = P_{4400} / F^{n_x}$$

Precipitation at the *quechua-suni* border at 3500 m, for example, would be calculated as:

$$880\text{ mm} / 1.03135^{(4400\text{ m} - 3500\text{ m})/50\text{ m}} \approx 505\text{ mm}$$

69 If a start capital K_0 accumulates to an end capital K_n in n years by adding yearly interests, then the interest rate p in % is calculated as: $p = [\sqrt{K_n/K_0} - 1] \times 100$. Since in case of the precipitation gradient the factor is not given in %, the formula could simply read: $p = \sqrt{K_n/K_0}$. The variables referring to financial calculations should be renamed, however.

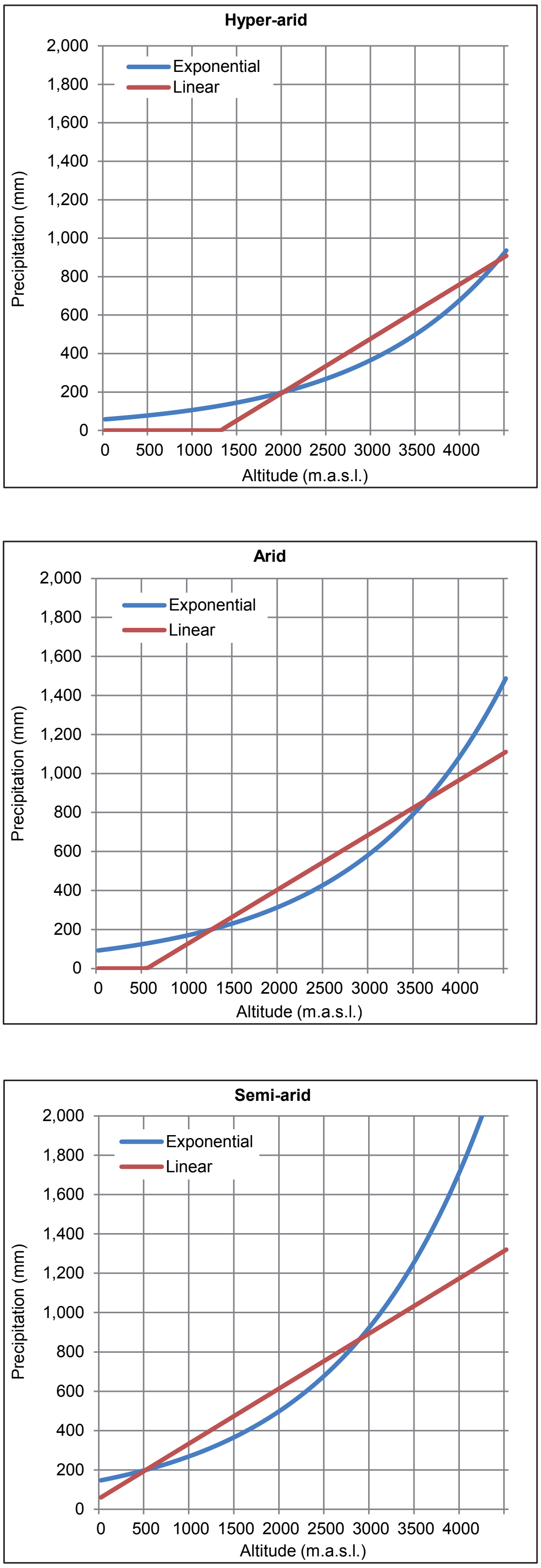


Fig. 9. Relation between altitude and precipitation after a linear and an exponential model under different climatic conditions. The terms hyper-arid, arid, and semi-arid refer to the assumed situation around the town of Palpa (350 m.a.s.l.). Graphics: VS.

The values for all ecozone borders are given in Tab. 1. In Fig. 9 the resulting graphs for the linear and the exponential model are compared.

In order to get an idea of the possible amplitude of the shifting of ecological zones through time, a comparison can be made with a well-known humid phase. The best data for such an epoch is available for the Late Intermediate Period (1000–1470 CE). At the site of Huayurí in the Santa Cruz valley, some ten kilometers west of Palpa, Bertil Mächtle et al. (2009) identified structures belonging to a *khadin*-like system for water harvesting which was radiocarbon-dated to 1262–1292 CE (Mächtle et al. 2012, Mächtle & Eitel 2013:66). Similar systems are in use today in other parts of the world, and it is known that they need a minimum amount of 100–150 mm of annual precipitation to work effectively (Mächtle et al. 2009). Mächtle et al. therefore deduce that in the second half of the 13th century CE precipitation at the altitude of Huayurí (500 m.a.s.l.) accumulated to about 150 mm per year. Today, the amount lies below 10 mm. It is probable that the actual precipitation even exceeded 150 mm during much of the LIP (Chapter 2.2.3). During the 14th century CE, the 200 mm isohyet marking the desert margin may have run through Huayurí along the 500 m contour or even at a lower altitude – a difference of 1500 altitudinal meters compared to today.

It can be assumed that all borders between ecological zones will also have shifted by 1500 m. This is obviously a simplification, though an inevitable one, because of the general paucity of meteorological data not allowing for a more refined model. If today's climate[70] is considered hyper-arid and the 14th century climate was probably semi-arid, then under arid conditions, the ecozone borders may have run roughly halfway (750 altitudinal meters) between both extremes (Tab. 1). Whenever the ecozone borders drop by more than 500 altitudinal meters, the *chala* merges with the *yunga* zone in terms of moisture conditions (Map 8), although, in reality, the very coast will have been a special case always due to the close-by ocean and its influ-

70 It has to be cautioned that Pulgar Vidal defined his ecozones in the late 1970, but given the pace of recent climate change, the situation may have changed noticeably during the last 40 years, creating a certain offset of perhaps a few dozen meters in the altitudinal limits. For now, I will assume that this offset is negligible, given the general uncertainties of the data.

		Monthly Minimum Temperature during Growing Season					
Station	**Altitude**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**AMMTGS**
Accnococha	4520 m.a.s.l.	-4.4 °C	-2.0 °C	-1.5 °C	-1.6 °C	-2.5 °C	-2.40 °C
Pisco	9 m.a.s.l.	17.9 °C	18.9 °C	18.7 °C	16.7 °C	14.4 °C	17.32 °C
Difference	*4511 m*	*22.3 °C*	*20.9 °C*	*20.2 °C*	*18.3 °C*	*16.9 °C*	*19.72 °C*
Temp. gradient		*0.0049 °C/m*	*0.0046 °C/m*	*0.0045 °C/m*	*0.0041 °C/m*	*0.0037 °C/m*	***0.00437 °C/m***

Tab. 2. Calculation of the temperature gradient during the growing season taking measurements between 1947 and 1961 from two stations in the Pisco valley as reference data (calculated values rounded). Table: VS.

ence on local wind, temperature, and moisture regimes. Accordingly, the presented models are more suitable for inland areas[71].

4.3.2 Temperature

Besides precipitation, the second crucial climatic factor for the agricultural potential of these ecozones is temperature. Although in the study area average temperatures have always been relatively high due to its proximity to the equator, the limiting factor for agriculture is nightly frosts at high altitudes during the growing season (January to May) which can cause severe damage to crops. The average monthly minimum temperatures during that period (AMMTGS)[72] can be regarded as the crucial factor. In the following, I will call the isotherm corresponding to 0°C AMMTGS the frost margin. *Average* means that frosts still do occur during some especially cold nights but they are relatively rare. Cultivation of frost tolerant crops, especially some potato varieties, should be possible at the frost margin and the risk of a dramatic failure due to frost damage in an exceptionally cold year is still passable.

Changes from cold to warm periods are generally even more difficult to reconstruct from geoarchives than shifts from humid to arid conditions. Although little is known about changing temperature patterns in the study area during the last 3500 years, it is unlikely that mean temperatures varied by more than a few degrees, judging from large-scale global and continental perspectives (Jones & Mann 2004, Kellerhals et al. 2010, Mann et al. 2008, Mann & Jones 2003, Negendank 2004). The changes of the day/night and summer/winter amplitudes, and thus of the extreme temperatures, due to orbital parameters and variations in sun activity may have been somewhat more pronounced (Dincauze 2000:149–152). Since regional temperature patterns may vary from generalized continental or global ones, preferably local archives should be used to investigate the development in the study area. Isotope analyses may give some hints but have not yet been realized.

In the case of temperatures, a linear relation to altitude can be assumed in broad terms, although local microclimates may deviate.[73] For the purpose of model building, a temperature gradient can be calculated by comparing 20th century data from the coast and from the highlands in a manner similar to the way the precipitation gradient was determined. The stations closest to the study area with a reasonably long observation period are Pisco (1948–1961) at 9 m.a.s.l. and close to the shoreline, and again Accnococha (1947–1961) at 4520 m.a.s.l. Accordingly, the altitudinal difference between both stations is 4511 m. At the former, the long-term AMMTGS is 17.32°C and at the latter -2.40°C. The temperature gradient can be calculated by dividing the temperature difference (19.72°C) by the altitude difference: $19.72\,°C / 4511\,m \approx 0.00437\,°C/m$ (Tab. 2). Taking the altitude of Accnococha as reference, the AMMTGS at any altitude can be interpolated by multiplying the altitudinal difference to Accnococha with the gradient, and adding the AMMTGS at Accnococha. In case of the *yunga-quechua* border, the formula would read: $(4520\,m - 2300\,m) \times 0.00437\,°C/m + (-2.4°C) \approx 7.30\,°C$ (Tab. 3).

Compared to the decades around 2000 CE, the 1950s, during which the reference data were generated, were a relatively cold phase, at least

[71] A complete table holding the interpolated values after the linear and the exponential model corresponding to 50 m altitudinal intervals can be found in the "Ecozone-Shifts" folder on the supplement DVD.

[72] Average Monthly Minimum Temperature during the Growing Season.

[73] See Barry 1992:259–266 for some case studies and an overview of factors causing deviations from a linear relation.

Borders between Ecozones	AMMTGS	Altitude (1950s)	Altitude AMMTGS +2 °C	Altitude MMTGS +1 °C	Altitude AMMTGS -1 °C	Altitude AMMTGS -2 °C	Altitude AMMTGS -3 °C	Altitude MMTGS -4 °C
frost margin	*0 °C*	*3971 m.a.s.l.*	*4428 m.a.s.l.*	*4200 m.a.s.l.*	*3742 m.a.s.l.*	*3513 m.a.s.l.*	*3284 m.a.s.l.*	*3055 m.a.s.l.*
chala-yunga	15.17 °C	500 m.a.s.l.	957 m.a.s.l.	728 m.a.s.l.	271 m.a.s.l.	42 m.a.s.l.	–	–
yunga-quechua	7.30 °C	2300 m.a.s.l.	2758 m.a.s.l.	2529 m.a.s.l.	2071 m.a.s.l.	1843 m.a.s.l.	1614 m.a.s.l.	1385 m.a.s.l.
quechua-suni	2.06 °C	3500 m.a.s.l.	3957 m.a.s.l.	3728 m.a.s.l.	3271 m.a.s.l.	3042 m.a.s.l.	2813 m.a.s.l.	2584 m.a.s.l.
suni-puna	-0.13 °C	4000 m.a.s.l.	4458 m.a.s.l.	4229 m.a.s.l.	3772 m.a.s.l.	3543 m.a.s.l.	3314 m.a.s.l.	3085 m.a.s.l.

Tab. 3. Assumed relation between the average monthly minimum temperature during the growing season and altitude under recent conditions and interpolated values for conditions between 2 °C warmer and 4 °C colder. Table: VS.

if seen from a worldwide perspective (Anderson & Goudie et al. 2007:194–197). The decade was nevertheless warmer than most of the 3500 years before. This, however, refers to annual *mean* temperatures and not to minima, which may have varied to a larger degree. For now it shall be assumed that the AMMTGS during the last millennia were probably rarely higher than 2°C or lower than 4°C, compared to the 1950s. This hypothesis remains to be tested against more concrete data (hopefully available soon).

The isohypse corresponding to a given temperature can be calculated by subtracting from the altitude of a reference station the difference of the temperature in question to that at the reference station, divided by the gradient. If the gradient stayed more or less stable over time, this calculation is also possible for temperature patterns different from that of the 1950s. Under conditions 4°C colder than in the 1950s, for example, the AMMTGS at Accnococha at 4520 m.a.s.l. would have dropped to -6.4°C. Taking Accnococha as reference, the isohypse marking the *yunga-quechua* border (AMMTGS = 7.30°C) should have run at 1385 m.a.s.l.: $4520\ \text{m} - (7.30\ °\text{C} - (-6.4\ °\text{C})) / 0.00437\ °\text{C}/\text{m} \approx 1385\ \text{m}$. The isohypses corresponding to the other ecozone borders can be determined accordingly and the same process can be repeated with different reference temperatures. Tab. 3 shows the results for AMMTGS values differing from those during the 1950s by +2 °C, +1 °C, -1 °C, -2 °C, -3 °C, and -4 °C.

4.3.3 Variability

The variability of climatic conditions directly affects the predictability of temperature and precipitation patterns in a given place. The more extreme and more frequent the deviations from the normal values, the higher the risk that a cultivated field will render no or only low yields due to frost damage or insufficient water supply. For rain-dependent farming, the risk increases with proximity to the frost margin or to the *yunga-quechua* border, corresponding to the 285 mm isohyet after the linear interpolation model and to the 241 mm isohyet after the exponential one (cf. Chapter 4.3.1). In the case of irrigation farming, the distance from the headwaters is crucial, as the discharge of a river will decrease the more fields are irrigated with its water along its upper course. In both cases, under unstable conditions fields in especially risky areas will be abandoned first. Population pressure may nevertheless force farmers to take high risks in the hope of a good year, but this means that in a bad year all or most of the seed deployed in risky areas is lost, resulting in a decrease of the average multi-year yield per unit of seed. With shrinking surpluses, capacities to build up buffer storage are also lowered, as is the amount of potential trade goods.

To get an idea of climate variability, attention should first be drawn to the situation during the 20th century, for which at least some data from meteorological measurements is available, though they are patchy and sometimes unreliable. Unfortunately, there are hardly any reliable multi-decadal data for temperature or precipitation in the highlands. The only information for the *cabezadas* above the South Coast available in the FAO database (FAO 2001) comes from the station of Accnococha in the headwaters of the Pisco river at 4520 m.a.s.l. For temperature, only the average monthly values for the years 1947–1961 are given, but not the individual values of each year. As a consequence, no statement can be made about the range of deviation from the norm and the frequency of extreme years.

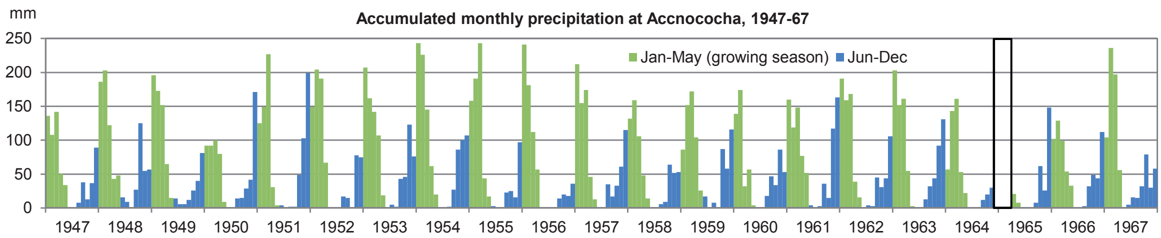


Fig. 10. Accumulated monthly precipitation at Accnococha after data derived from the FAO database (FAO 2001). The data between December 1964 and March 1965 are missing. Graphic: VS.

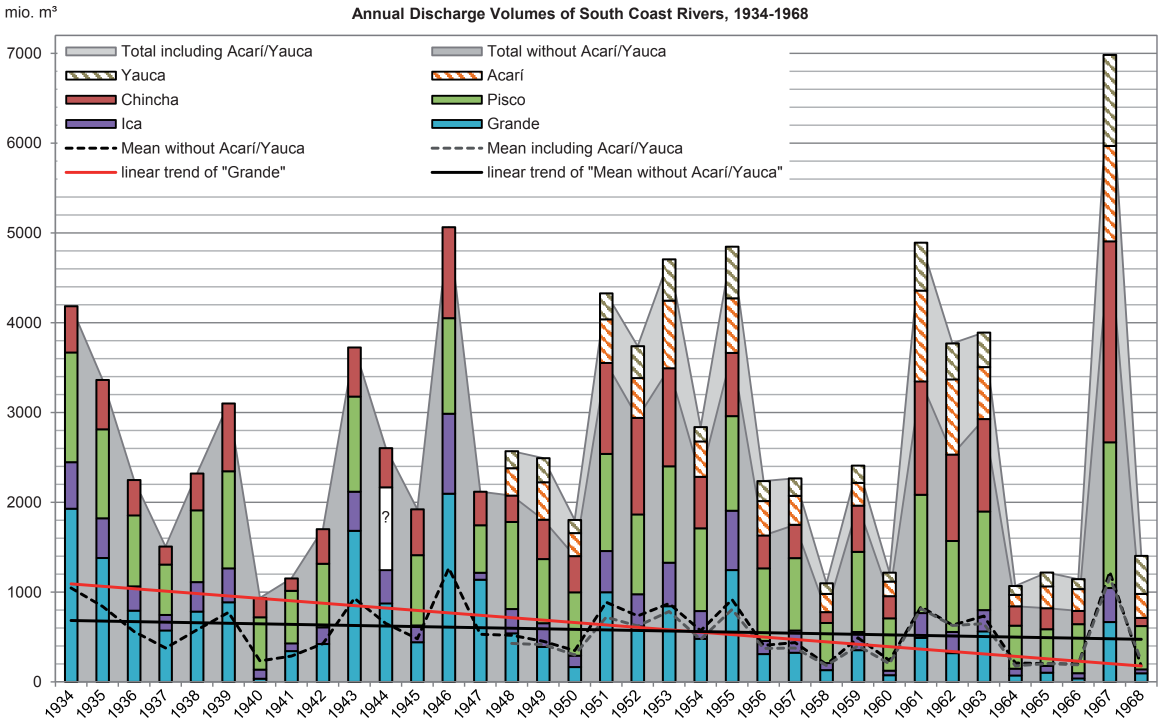


Fig. 11. Annual discharge volumes of South Coast rivers between 1934 and 1968 after the data published by ONERN (1970/1971a,b,c/1975). Note the significant inter-annual and inter-drainage variabilities. The general long-term trend shows a decrease in discharge for all rivers but in particular for the Río Grande. Graphic: VS.

Fortunately, at least the accumulated monthly precipitation for the years 1947–1967 was recorded for each month separately. As can be seen from Fig. 10, the values vary considerably from month to month and from year to year. For example, in 1950 precipitation did not exceed 100 mm per month even at the height of the rainy season (February/March), but it also never dropped below 80 mm for four months (January to April), providing a stable water supply. In turn, in 1955, precipitation was abundant between January and March but dropped below 50 mm in April. This distribution had limited the available irrigation water just during the last weeks before harvest. In terms of agriculture, a pattern similar to 1950 is more favorable, although the accumulated yearly amount of 644 mm was much lower than in 1955 (818 mm).

For the lack of a close-meshed grid of meteorological stations with reliable data from a multi-decade observation period, the river discharge volume may serve as a proxy instead when comparing drainage systems. The discharge depends on local rainfalls in the highland catchment area and has been measured more or less continuously for most rivers since the 1930s. The data published by ONERN in the 1970s (1970/1971a,b,c/1975) can be used to compare the diverse South Coast valleys. Fig. 11 shows the combined annual discharge volume of all major South Coast rivers for the 35-year period between 1934 and 1968, except for the Acarí and Yauca rivers for which data is only available from 1948 onward.[74] If the latter two are not considered, the values vary between 714 mio m³ (1968) and 5065 mio m³ (1946). This means that the volume of the most humid year exceeds that of the driest year by seven times. The seesaw pattern with the irregular succession of relatively moist and very dry years illustrates well the general unpredictability of precipitation levels.

The amplitude of inter-annual changes is not uniform throughout the South Coast but differs from drainage to drainage. This phenomenon, however, likely mirrors the individual extent, topography, and water storage capacity of the respective catchment areas rather than local differences in rainfall. The amount of precipitation that evaporates or is stored in soils and plants is a rather stable absolute value while the total rainfall varies considerably. As a consequence, if precipitation decreases in absolute terms the relative share that runs off into a river decreases as well. Accordingly, variations in runoff volume will be more extreme in the drainages of minor rivers with a low absolute discharge volume. From 1934–1968, the climate became drier and the mean annual runoff of all South Coast rivers dropped slightly (Fig. 11, black line). In case of the Río Grande drainage (as a whole) this development is much more pronounced (red line) because its discharge volume is below the average. Drier conditions therefore affect the availability of irrigation water to a greater extent than, for example, in the Pisco valley.

Altogether, it can be assumed that 20th-century precipitation patterns were relatively variable in a multi-millennia perspective, but this has to be considered a hypothesis as long as no high-resolution data is available for the more distant past. As temperature and precipitation are two closely linked factors in the climate system, the same statement could be made for temperatures.

4.3.4 The Potential of Irrigation Agriculture

Irrigation agriculture at the valley floors is generally more productive than the rain-dependent highland farming but it is limited by the amount of cultivable land and the availability of river water. The extent of the valley floors restricts the area that is potentially irrigable and the discharge volume of the rivers determines the potentially available irrigation water. The latter is directly related to precipitation patterns in the highland catchment area. If the runoff exceeds the optimal amount needed for irrigation, the excess will just flow into the ocean and is of no productive use. On the other hand, if the water does not suffice to irrigate all of the potentially cultivable land, some fields will render no yield. The temporal distribution of the annual discharge is also crucial: if runoff is extremely high for a few weeks and then rivers fall dry, the short-time abundance is of no use during the following dry period and crops may wither before harvest. A lower total amount of water evenly apportioned throughout the growing season can hence be much more helpful.

Today, large artificial reservoirs can balance the fluctuations to a certain degree. Additionally, massive ground water tapping with the help of motor pumps plays on increasingly prominent part in water supply.[75] There is some pre-Hispanic evidence of diverse installations for the storage of water by conducting it on terraces or sediment-filled quebradas closed by a bund where it seeps into the soil.[76] Furthermore, ground water tapping had already been practiced in the SGD since Nasca times with the help of filtration galleries, the so-called *puquios* (Schreiber & Lancho Rojas 2003). Both water storage and ground water extraction nevertheless will have been of a rather small scale when compared to today's situation.

In order to get an idea of the availability of land and water in different South Coast valleys, the data published by ONERN in the 1970s (1970/1971a,b,c/1975) is most helpful, not only because it is sufficiently detailed and considers observation periods of at least two decades but also because at this time the impact of modern modifications by canal construction and terrain leveling with the help of heavy machinery and explosives was still relatively limited. In effect, this data is more suitable for projections into pre-Hispanic times than very recent one.

Fig. 12 shows the mean annual discharge volume of the major South Coast rivers, the potentially cultivable land, and the relation between volume and irrigable land. The poten-

[74] The data and charts presented in this and the following sub-chapters can be found in the Excel® workbook "AgriculturalPotentialSouthCoast.xlsx" in the "ClimateData" folder on the supplement DVD.

[75] Many wells are now being drilled more than 100 meters deep. In recent years, ground water extraction significantly exceeds the natural refilling capacities, resulting in a lowering of the ground water table at a dramatic pace, especially in the Ica valley, where it currently drops by more than a meter per year (Hepworth et al. 2010).

[76] E.g., the Khadin-like system at Huayurí in the Santa Cruz valley mentioned in Chapter 2.2.3 (Mächtle et al. 2009/2012).

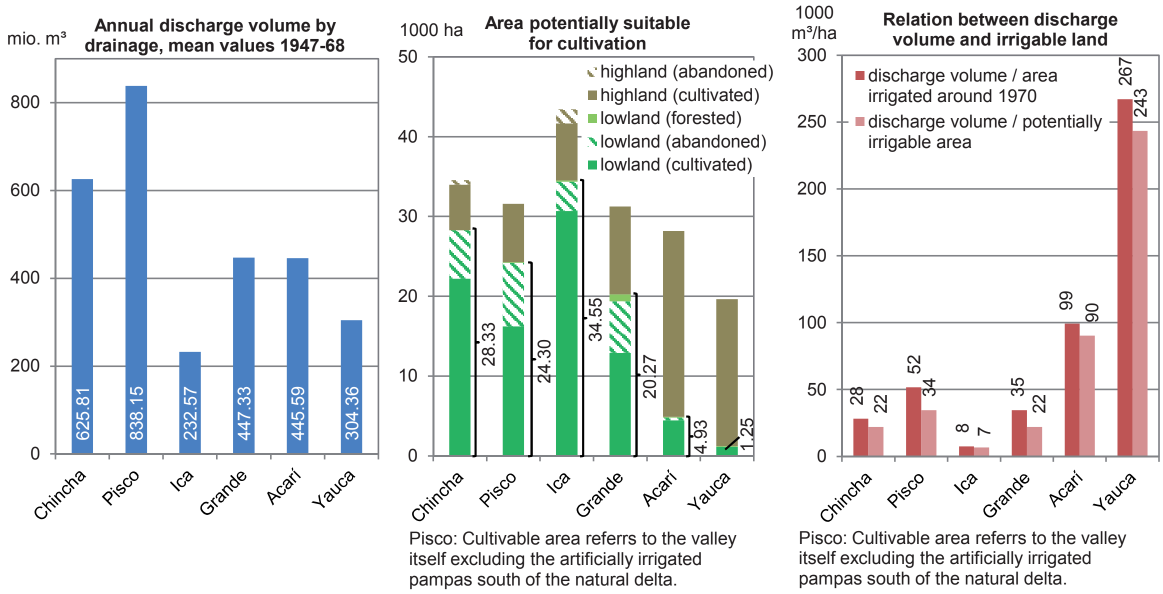


Fig. 12. Comparison of South Coast valleys: Mean annual discharge volumes of rivers, calculated for the period 1947–1968, and cultivable land as around 1970 after data published by ONERN (1970/1971a,b,c/1975). Graphics: VS.

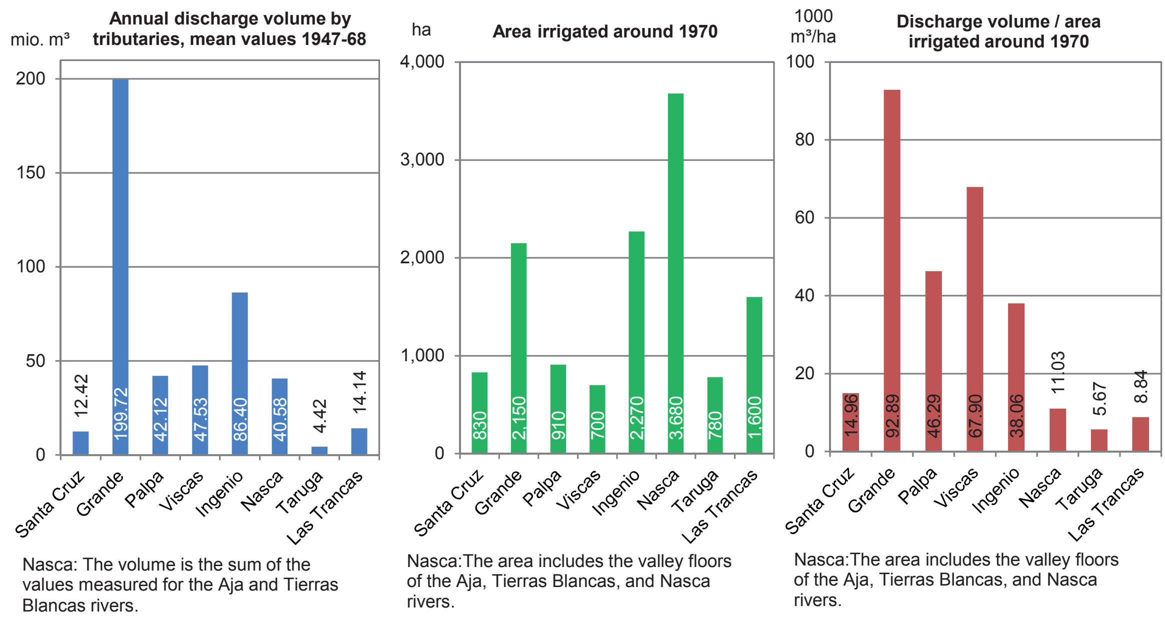


Fig. 13. Comparison of the eight major valleys of the Río Grande drainage: Mean annual discharge volumes of rivers, calculated for the period 1947–1968, and irrigated land as around 1970 after data published by ONERN (1971a). Graphics: VS.

tially irrigable land comprises the lowland valley floors, including the small portions of remaining riverine forests. Some fields had already been abandoned before 1970 due to problems of water supply or salinization. The relation between discharge volume and irrigated or potentially irrigable area may serve as an indicator for the relative vulnerability of local agriculture to droughts, though it cannot serve to determine the amount of irrigation water actually available because it does not reflect its distribution over an entire year. The figure illustrates that in the valley with the highest runoff, the Pisco valley, comparatively few land is available.[77] In

[77] ONERN (1971c) distinguishes between the "valle viejo", which is the Pisco valley proper, and the "Pampas de Lanchas y Santa Cruz" in the desert just south of the river delta which could not have been claimed without motor pumps. For the purpose of this study, only the "valle viejo" has been considered, as it roughly corresponds to the area which could also have been irrigated in pre-Hispanic times.

Ica, in turn, where the most extended cultivable area can be found, the hydrological resources are lowest. In Acarí and Yauca, the absolute area suitable for irrigation is so small that rain-fed agriculture will always have predominated, but at least the few irrigated fields available were not ever likely to suffer from water shortages, particularly in Yauca.

Under stable, semi-arid conditions, when the discharge volume of all rivers suffices to water all irrigable fields in the respective valleys throughout the growing season, Ica has the highest potential for irrigation agriculture, followed by Chincha, Pisco, and the Río Grande drainage (as a whole). Under dry or variable conditions, in contrast, after Yauca and Acarí, it is the Pisco valley where harvests can be expected to be most reliable (though limited in quantities), followed by the Río Grande drainage and Chincha. Ica, in turn, is now becoming the by far most precarious valley of all. This is very important to understand when regarding possible inter-drainage population shifts on the South Coast in pre-Hispanic times.

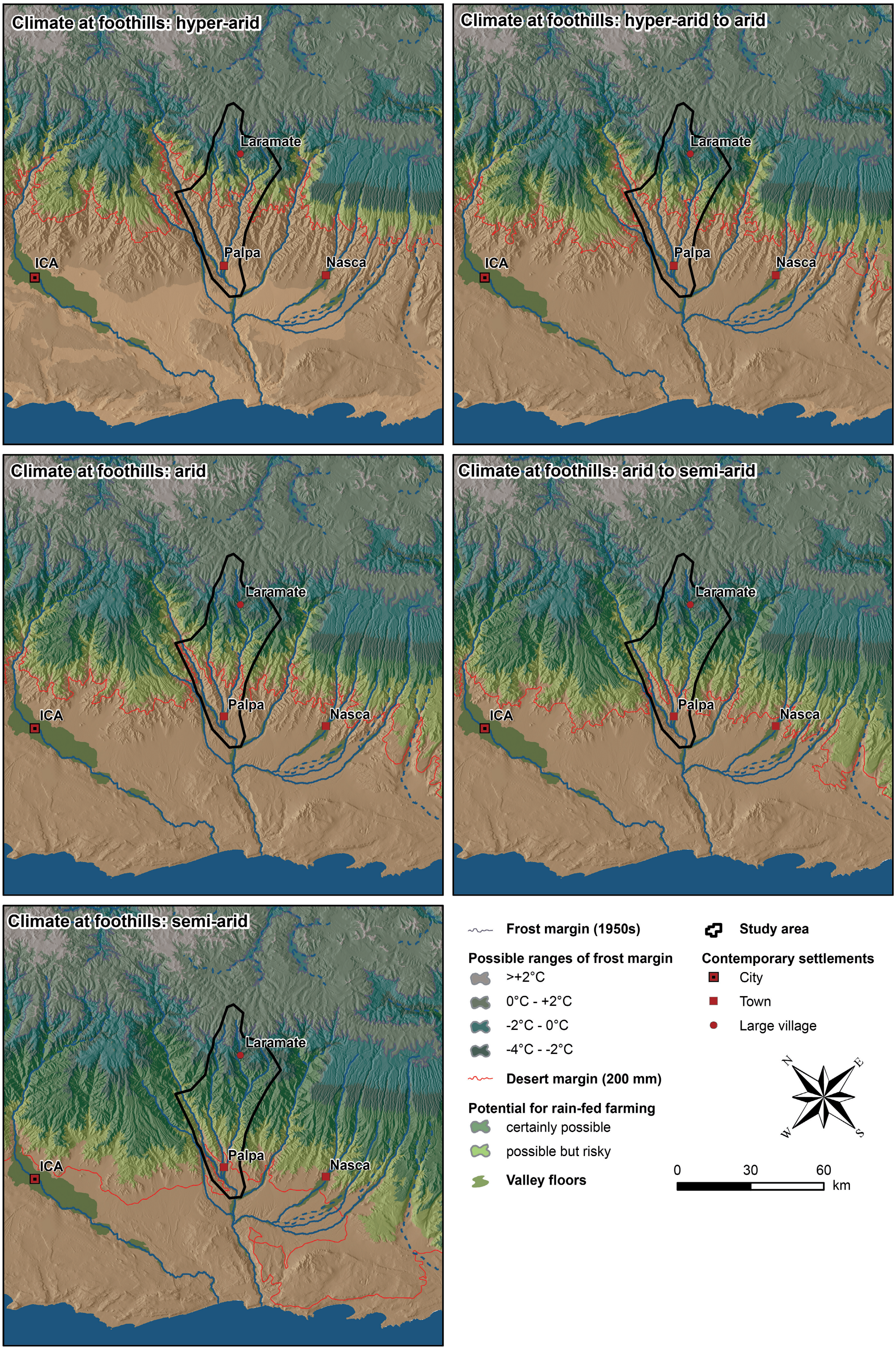
The Río Grande drainage is a special case in that it consists of eight major branches (lumping the Río Nasca with its two tributaries, the Río Aja and the Río Tierras Blancas). Each of these branches shows a very different sensitivity to water shortages as illustrated in Fig. 13. While in the Río Grande valley itself the volume/irrigation area relation is comparable to that of the Acarí valley, and the Palpa, Viscas, and Ingenio branches still have values significantly higher than that for Chincha, the entire SGD is as vulnerable to dry conditions as is Ica. Even the Santa Cruz valley, by far the driest branch of the NGD, still has more potential than the most productive of the southern valleys (Nasca, including Aja and Tierras Blancas). It seems therefore logical that the Nasca-era *puquios* were constructed in the SGD (Schreiber & Lancho Rojas 2003), while no such facilities are known from the NGD.

While the potential for irrigation agriculture in the Río Grande drainage as a whole takes an intermediate place in a South Coast comparison, the differences between its northern and its southern branch are enormous. While the north is among the valleys with the best water supply, the south is most vulnerable to dry conditions. Accordingly, for pre-Hispanic periods, climate related intra-drainage population shifts have to be considered possible or even likely.

4.3.5 The Agricultural Potential under Different Climatic Conditions

Each of the three basic climatic factors – precipitation, AMMTGS, and variability – changed through time causing the agricultural potential to fluctuate as well. Furthermore, rain-dependent highland farming and irrigation farming at the valley floors are affected differently by changing parameters. The average monthly minimum temperature during the growing season and local precipitation patterns restrict the potentially suitable areas for highland agriculture. Rain-fed farming is theoretically possible below the frost margin and above the *yunga-quechua* border, that is, above the ≈250 mm isohyet. In praxis, a minimum of 350–400 mm of annual precipitation is more realistic, because below this amount, the risk of crop failures in years with below-average rainfall is very high (see Chapter 4.3.1). The respective isohyet corresponds roughly to the 3000-m-isohypse. Since factors like soil quality and slope have to be considered as well, only a small fraction of the delimited zone will actually be cultivable. Irrigation farming, in turn, is only possible at or close to the valley floors, which are located below the frost margin even under cold conditions. The limiting factor here is the amount of river water which can be conducted to the fields. Map 8 displays changes in the extent of the potentially cultivable area under different climatic conditions. When combining the factors precipitation, AMMTGS, and general climate variability, conditions may have shifted between the following eight extreme scenarios:

1) *Semi-arid, warm, and stable:* These are the best conditions for farming societies. Precipitation is sufficient, regular, and reliable at altitudes down to 1500 m.a.s.l. and even lower, allowing rain-fed terrace farming all along the valley slopes. Several *quebradas*, which do not carry water today, turn into small rivers allowing irrigation in some lateral valleys. At the same time, the frost margin shifts upward to about 4200 m.a.s.l., or even higher, allowing farming in the *puna* where much more flat or only slightly inclined terrain (requiring less investment in terrace construction) is available than in the valleys. The low inter-annual variability and hence the predictability of climate minimizes losses due to extreme weather events and almost all fields will generate a satisfying harvest during most years.



Map 8. Areas potentially suitable for agriculture under hyper-arid, arid, and semi-arid conditions, according to the values given in Tab. 1. The upper limit is determined by the AMMTGS and may have fluctuated considerably (Tab. 3). Maps: VS.

2) *Hyper-arid, warm, and stable:* Precipitation is limited but reliable. Rain-fed farming is risky below 3000 m.a.s.l. and definitely impossible below 2300 m.a.s.l. but can be practiced at high altitudes. Only the major rivers provide sufficient irrigation water for the cultivation of the valley floors. Alltogether, the potentially arable area is drastically reduced compared to scenario 1), but at least the fields still under cultivation generate a reliable harvest.
3) *Semi-arid, cold, and stable:* There is sufficient and reliable precipitation but the frost margin has shifted downwards to about 3000–3500 m.a.s.l. Consequently, the area which today falls within the *suni* and *puna* zones and even the more elevated parts of the *quechua* have become unsuitable for cropping due to frequent frosts. They nevertheless still provide vast and rich pasture grounds for camelid herding. At the lower reaches down to 1500 m.a.s.l., in turn, rain-fed terrace cultivation is possible, which complements the highly productive irrigation farming at the valley floors, including some smaller *quebradas*.
4) *Hyper-arid, cold, and stable:* Precipitation is so sparse that reliable rain-fed cultivation would only be possible above 3000 m.a.s.l., but at the same time, the frost margin at 3000–3500 m.a.s.l. only leaves small patches here and there where water suffices *and* temperatures are high enough. Additionally, irrigation farming is limited to the valley floors of the major rivers while smaller *quebradas* fall dry. Despite the drastic restrictions, conditions are at least stable and the worked fields can be expected to generate a reliable harvest.
5) *Semi-arid, warm, and variable:* The general conditions are similar to those in scenario 1), but there is a high risk of occasional droughts, of summer rains being too hefty, starting too late, or ending too early, and of abnormal frost events. In good years, harvests are abundant, but in bad years, they may fail almost completely. Furthermore, a series of subsequent bad years may occur. In this scenario, a sophisticated risk management including extended storage, economic diversification, and tight reciprocal exchange relations with groups in potentially unaffected, distant areas are crucial.
6) *Hyper-arid, warm, and variable:* Even though the high frost margin allows farming in much of the highlands in good years, this is a highly risky enterprise because years with abnormally strong frosts are frequent. In these cases, a good part of the harvest is lost. At the lower reaches, where there is no frost risk any more, insufficient, too heavy, or badly timed rainfalls have to be taken into consideration. In the worst case, frosts and unfavorable precipitation occur in the same year, reducing the agricultural output to almost nothing. Under these conditions, societies dependent on farming are extremely vulnerable because even in good years the expected surplus, which could be stored for worse times, is minimal.
7) *Semi-arid, cold, and variable:* This scenario is almost as critical as scenario 6). Even though precipitation generally allows thriving rain-fed and irrigation farming at the lower reaches, abnormal irregularities in rainfall patterns may, in some years, destroy the biggest part of the harvest. At altitudes close to the low frost margin, unusual frosts can occur any time. The normal production is probably a bit higher than in 6) but the risk of crop failures and hence the vulnerability of farmer societies is almost as severe.
8) *Hyper-arid, cold, and variable:* This is the worst scenario of all. Not only is the suitable area for agriculture as restricted as in scenario 4), but additionally, large parts of the harvests are frequently destroyed by abnormally hefty or lacking precipitation and unpredictable frosts. Under these conditions, only small patches of the best land in zones of lowest risk can be farmed with ongoing success. As a consequence, population density has to be kept extremely low.

As outlined in the previous chapters the respective South Coast drainages will have been affected differently by these scenarios. Under semi-arid conditions, the valleys with the most extended floors, such as Ica, are especially favored while hyper-aridity will be most severe where the land/water relation is worst. A high AMMTGS has little impact on irrigation farming but may push the limits of rain-fed farming far into the *puna*. Drainages with small valley floors but extended *cabezadas* sections, like Acarí and Yauca, will therefore profit disproportionately. Today's conditions most likely fall into scenario 6). Although reliable data is sparse, it seems that the last two decades tended to be dryer, warmer, and less stable than the early and mid-20th century, but the difference can still be regarded as gradual. Accordingly, at least the last 100 years, but perhaps also the preceding centuries, will have tended towards scenario 6).

In Chapter 2.2.3, I summarized the current state of research on climate conditions in the study area during different sections of the past. If the reasonable assumption is correct that farmers generally tended to dwell near their fields, then the establishment of villages in certain areas and the abandonment of others elsewhere may be related to climate-induced changes in the agricultural potential. If indicators of conflict in the archaeological record correlate with worsening conditions for cultivation, such conflict may have rooted in struggles for diminishing resources. In order to assess whether major changes in settlement behavior could have been related to climate change, it is now necessary to review and classify the respective archaeological data and to discuss adequate methods for a reconstruction of basic parameters in human (pre-)history.