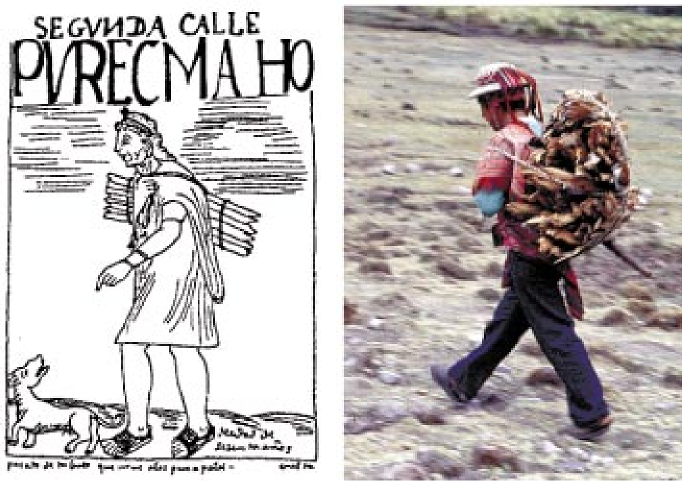
Article **Alex Chepstow-Lusty and Mark Winfield**

Inca Agroforestry: Lessons from the Past

Historical accounts of the Inca indicate that they greatly valued trees and practiced planting to fulfil their needs for fuel and timber. These records are evaluated in the light of palaeoecological and archaeological evidence suggesting a dramatic increase in arboreal taxa from c. AD 1100 during a period of significant global temperature increase. This natural vegetation response to improving environmental conditions may have stimulated management; it is suggested that agroforestry has a long tradition in the Andes. With the arrival of the Spanish, in the 1530s, land management practices changed and forest resources became increasingly overexploited. A multidisciplinary approach may provide important lessons from the past for modern policy makers in Peru. Widespread planting of *Eucalyptus* may not be an appropriate solution. Land restoration projects should take account of natural diversity and utilize a range of native species. This is relevant in view of the current period of rising temperatures, and may help to alleviate both soil erosion and rural poverty.



The unchanging Andean lifestyle; a peasant carrying a *fardo* of wood, in an etching by Guaman Poma in 1615 AD (13), and his modern day counterpart. Photo: C. Aucca Chutas.

INTRODUCTION

The environmental and social problems of Peru, and the Andes in particular, are typical of many areas that have become heavily degraded as a result of human activities. According to figures published by the Department for International Development in the UK, of the 24 million people living in Peru 49% live in poverty (1, 2). The poorest groups are the indigenous peoples living in the rural Andes (an estimated 66% of households are classified as poor). Rural depopulation and migration into urban areas are directly related to the inability of the landscape to sustainably support a large population; major causal factors are environmental: deforestation, soil erosion, poor water management and soil infertility. The creation of a cash economy has also changed the way in which resources are valued and shared, and has polarized division within rural communities and between rural and urban areas.

Before the arrival of the Spanish in the 1530s, the Inca Empire stretched from southern Colombia to central Chile, and may have supported 30 million people (3, 4). It has been estimated that the Inca cultivated as many as 70 crop species (5). Their storehouses were said to hold enough supplies to sustain the population for up to 10 years. The conquest by the Spanish resulted in a major breakdown of the infrastructure for managing the landscape, and a rapid population decline, mainly caused by new diseases. It has been estimated that within a century of colonial rule, the indigenous population in Peru collapsed from 9 million to 600 000 (6). The results of a census taken in 1950 estimated that the population was still below 8 million (2).

The Spanish redistributed the available resources, taking the most fertile lands for themselves. The indigenous population was forced into less productive areas, such as the higher altitudes, without access to the wide range of ecological zones that they had previously had. With the introduction of Eurasian domesticated mammals and crops, and the high demand for timber, a major decline in biodiversity, soil degradation and an undermining of watershed protection were inevitable. Unlike the Spanish, the Inca may have managed the environment successfully, using practical methods that worked to boost food production and to control soil erosion. These involved the building of terraces, irrigation systems, as well as close control of the population.

In this case study, we critically examine the hypothesis that the Inca practiced agroforestry as a means of controlling wood supplies, but also to stabilize soils. To test this, we will use historical documents as the basis, and make a comparison of evidence from a range of disciplines: palaeoecology, archaeology and contemporary sources. This allows the possibility of independently corroborating these historical accounts, as well as reaching back into the period before documentation. The people giving rise to the Inca had probably been in the area for several centuries before the rise of the Inca Empire (AD 1470–1536), as shown from pottery styles (7, 8). It was their land-management practices that the Inca were to adopt and build upon. We are particularly interested in the period beginning c. AD 1100 in relation to evidence of early tree planting or natural reforestation.

HISTORICAL EVIDENCE

As the Inca had no written language, direct environmental information is not available until after 1530 and is limited to accounts in Spanish by native and Spanish chroniclers. When the Spanish arrived, they observed essentially bare hillsides with a few patches of trees (9). However, they reported finding thousands of Inca state storehouses, or *qollqa*, containing abundant food supplies (estimates indicate enough for up to 10 years) and a range of fuels including split logs (*lena rajada*). Inventories of the contents of these stores were kept by Andean officials on *quipu*, a mnemonic method of knotted strings. The Wanka, a tribe that had been conquered by the Inca c. 1460, formed an alliance with the Spanish and furnished them with all necessary requirements. The *quipu* records of these supplies survived and, in 1561, were presented by the Wanka leaders at the *Audencia*

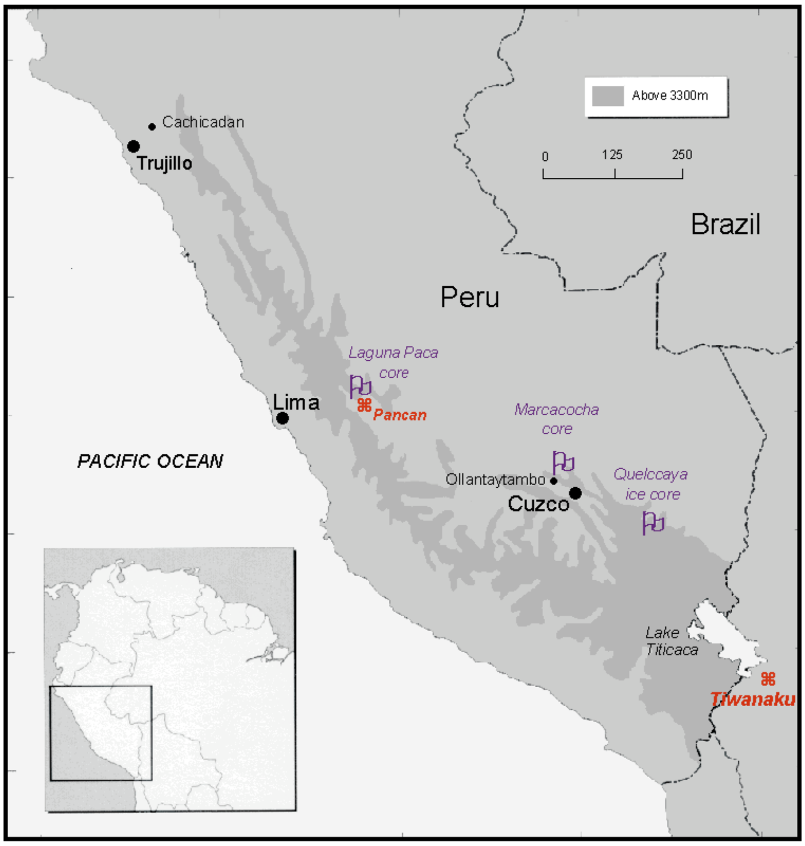


Figure 1. Sites mentioned in the text.

de los Reyes in Lima and transcribed into Spanish. From the northern end of the Mantaro Valley, a defined Inca administrative unit (Hatun Xauxa, close to Laguna Paca), 200 071 loads of split logs were given to the Spanish in 1533 (10–12). Today, a load, or *fardo*, is equivalent to the bundle that can be carried on one's back (13), and weighs c. 12–15 kg. By 1537, this supply had dramatically declined to 17 000 loads. These records probably reflect a rapid decline in readily available wood resources. Deforestation in certain areas may have occurred rapidly. Henestrosa (14) records that a lack of firewood in the valley was one of the reasons for Francisco Pizarro leaving Hatun Xauxa, to settle in Lima in 1535, after being there for only 2 years. In 1639, a century after the Spanish conquest, Padre Cobo remarked that a Spanish household used as much fuel in one day as would an Indian household in an entire month (15).

Prior to the arrival of the Spanish, the ability of the Wanka to supply such large quantities of logs as tribute to the Inca, in addition to provisioning their own needs, suggests woodland management. Although the species of trees used as a source of wood are not defined in the *quipu*, aliso (*Alnus acuminata*) may have been an important component of the *lena rajada*. Documentary evidence clearly shows that aliso was planted in the area, and that it was a much reduced resource 50 years after the Conquest:

"...in the valley there are not more than two kinds of trees of the countryside; one is aliso and the other is quishuar (*Buddleja* spp.), as it is called by the Indians; and this (sic.) is planted by hand and brought in from outside for use in their houses and church buildings, so that with effort enough wood can be found for them..." (14)

An account of the 7th Lord Inca, Viracocha Inca Yupanqui, by the native chronicler Pachacuti Yamqui, indicates how important aliso and other trees were, both symbolically and economically, to the Inca and their descendants:

"...they say that he was gentle; his occupation was to build houses, and the fortress of Sacssaguaman, (adjacent to Cuzco) and also the fields and the planting of alisos and other plantings of quishuar and chachacoma (*Escallonia* spp.) and molles (*Schinus molle*)..." (16).

The antiquity of tree planting in Andean tradition is rooted in the richness of the Quechua language, with such words as *mallqui*, meaning a cultivated tree as opposed to *sacha*, a wild tree. Fortunately, this diversity of language was recorded in Holguin's 16th century Quechua dictionary, which shows the word *mallqui* being used in a range of phrasal constructions such as *Ppitticta cassacta mallquipani* meaning to transplant trees to where they are lacking (17). *Mallqui* can also mean a dead ancestor (18), which indicates the reverence in which they held their forests. Forests were state property in Inca times and people who damaged them were brought before a special authority, *mallki kamayoc*, for sentencing (19). Punishments were very severe and may have included the death sentence (13).

Firewood had a symbolic role in Inca culture: at weddings of high officials, logs were gilded to appear as if made of solid gold and presented as gifts (19). At more ordinary weddings, Murua (19) records, besides bringing the bride gifts of meat and coca, they brought "firewood of some roots called Urutne (?) or if they didn't have that, of aliso made into logs..."

In spite of the value of trees to the native people, after the collapse of the Inca empire, the Conquistadors made excessive demands on the available resources. Not long after their arrival in Cuzco, the Spanish had cut down most of the molle (*Schinus molle*) trees as they were an excellent source of charcoal (20). The Spanish, however, soon became aware that replanting was necessary and, in 1590, they initiated a program to reforest 60 km of the valley near Cuzco. Although on a relatively small scale, the 2400 trees planted under Spanish supervision included the four species Quishuar (*Buddleja*), Chachacomo (*Escallonia*), Aliso (*Alnus*) and Q'euna (*Polylepis*) (18). This scale of planting, however, would not have provided a sustainable resource given the large demand for wood: fuel for smelting, brick and lime manufacture, breadmaking, and Mediterranean-type stoves.

From the available historical records, there seems little doubt that the Inca highly valued their forest resources, and to some extent carried out planting. Is there any independent evidence that throws light on the extent and nature of this?

PALAEOECOLOGICAL EVIDENCE

The recently infilled sacred lake of Marcacocha, (3300 m a.s.l.) lies 12 km north of the Inca town of Ollantaytambo and the Sacred Valley in the Cuzco region (Fig 1). Analysis of pollen from the 6.3 m core of organic lake muds (gyttja) extracted in 1993 has provided a high resolution environmental record covering more than 4000 years (21–23). This is a particularly important and rare site to be found at this low altitude: it is the only site that has been examined from the Cuzco region. Much effort has been invested into refining the resolution in order to integrate this information with the rich archaeological remains of the area; the sampling interval averages less than 50 years from c. 1100 AD until the present. Almost all previous palaeoecological in-

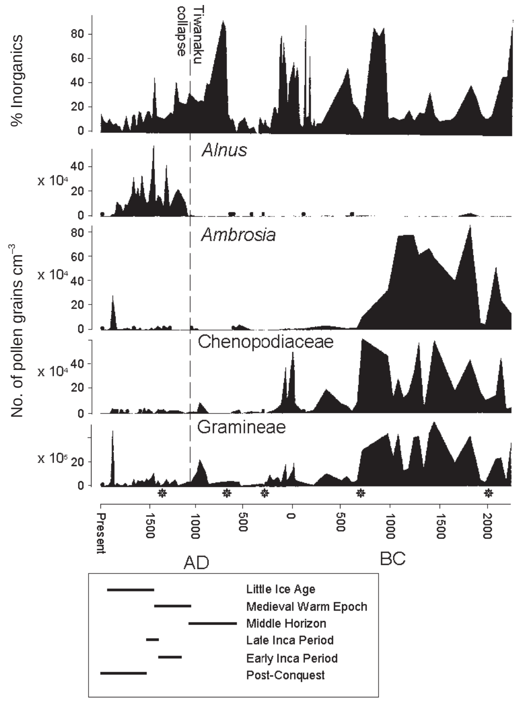


Figure 2. Pollen concentration diagram of 4 selected taxa from the Marcacocha record. The reappearance of aliso (*Alnus*) after 1100 AD, representing most of the arboreal signal, is the first sign of tree recolonization in the 4000 year record in a deforested agricultural landscape. This event is compared with the Inca chronology of Rowe (8) and the declining inorganic content, indicating a possible stabilization of erosion in the catchment. Other events, including the Medieval Warm Epoch and the collapse of the Tiwanaku civilization, are also shown. The symbols above the timescale show the position of the calibrated radiocarbon dates. Significant Andean crops within the family Chenopodiaceae, include *Chenopodium quinoa*. The shrub, *Ambrosia arborescens*, is an indicator of soil erosion, and the Gramineae (grass family) may be representative of land available for grazing.

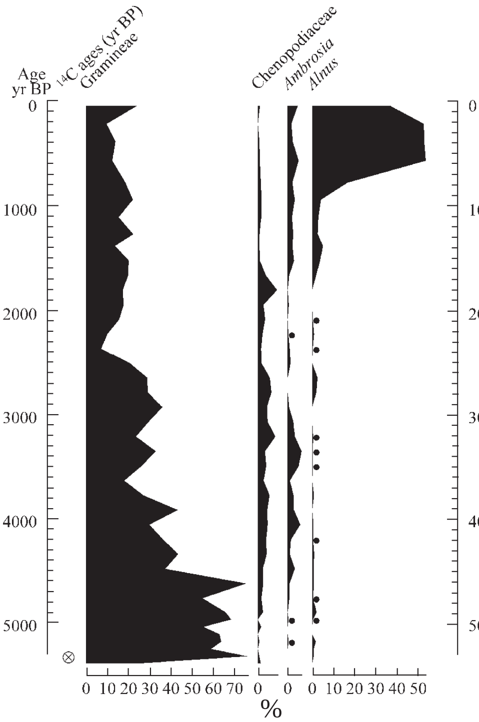


Figure 3. Pollen percentage diagram of four selected taxa from Laguna Paca in the Junin area. Notice the marked expansion of aliso (*Alnus*) in the last 1000 years (24).

vestigations of the Holocene record from lakes of the Central Andes have come from above the forest limits, at altitudes greater than 4000 m (24). Marcacocha was a small lake (c. 40 m diameter), making it particularly sensitive for recording local terrestrial vegetation changes using pollen analyses, in comparison with investigations from large lake basins. The highly organic lake mud of the core provides an internally consistent series of five radiocarbon dates that make it possible to accurately date major environmental changes. Inca and pre-Inca terraces, as well as numerous other archaeological remains surround the site, including the adjacent promontory of Juchuy Aya Orqo, containing occupations dating over 2700 years.

The pollen record (Fig. 2) indicates that, even before 4000 years ago, the Andean landscape was highly agricultural and essentially cleared of trees; arboreal pollen are extremely rare (21–23). Important crops included pseudocereals such as quinoa (*Chenopodium quinoa*) of the family Chenopodiaceae, associated with *Ambrosia*. There is only one species of *Ambrosia* in the region, *A. arborescens*. This naturally favors disturbed ground, and is used in the Andes today for stabilizing rudimentary terracing as well as being burnt as a fuel (25); presumably it performed a similar role in the past. Of particular interest, however, is the abrupt appearance of native alder, known commonly as aliso (*Alnus acuminata*), from AD 1100. This may indicate localized colonization by aliso in the vicinity of the lake, or it might represent a wider regional signal. Since there is no change in lake sediments from organic muds to peat at this interval, this is not colonization of aliso on peats as the lake became infilled. Indeed, infilling only occurred in the last 30 years according to local people (pers. comm.). Aliso does not occur close to Marcacocha today. It only survives as patches along the Patacancha Valley. The palaeoecological record demonstrates that, in spite of a rapidly growing human population, and presumably, therefore, increasing wood consumption, aliso densities remained relatively constant.

The only other site with which the vegetation record of Marcacocha can be directly compared is Laguna Paca (3600 m a.s.l.), at a somewhat higher altitude, but still below the treeline. This is located near the archaeological site of Pancan, further north in the Upper Mantaro river valley (24). Like Marcacocha, this is a relatively small lake basin suitably located in an area sensitive to recording environmental changes, and composed of almost 7.5 m of entirely organic lake muds (gyttja). Laguna Paca supports the evidence that there was a marked increase in aliso, from approximately 1000 years ago, followed by a period of stability (Fig. 3). This might indicate a local colonization of aliso, but its sustained presence is noteworthy in an area where demands for aliso are known to have been high as shown from historical documents. Unfortunately, the Laguna Paca core was sampled at lower resolution than that from Marcacocha and has only a single radiocarbon date (5303 ± 90 yr BP) at the base of the sequence from which all the other dates up to the present have been interpolated. This would be an excellent site to examine at a higher resolution.

Aliso may have recolonized these areas during the warm global climatic interval frequently referred to as the Medieval Warm Epoch (26). This event brought about a protracted drought and may, to some extent, be responsible for the collapse of the Tiwanaku civilization further south (27, 28). There is clear evidence of hiatuses and other sedimentological changes indicative of low lake levels in Lake Titicaca, as well as large-scale abandonment of surrounding raised field systems during the period c. AD 1100. This is further supported by a major decline of ice accumulation at this time in the Quelccaya ice-core record (Fig. 4), an indicator that precipitation was markedly reduced (29).

The palaeoecological record unfortunately does not give clear evidence of the presence and abundance of all native tree species, since many are insect pollinated and there is consequently a low probability that their pollen will be deposited in lake sediment. That aliso was present, and increasing in abundance, is clear however, since it is wind pollinated, and its pollen are well represented (Fig. 5). In order to gather more reliable information, as well as greater taxonomic resolution on many of the other species, larger pollen counts are required. An examination of a number of sites across a wide geographical area and a range of altitudes would clarify the extent and diversity of trees used by

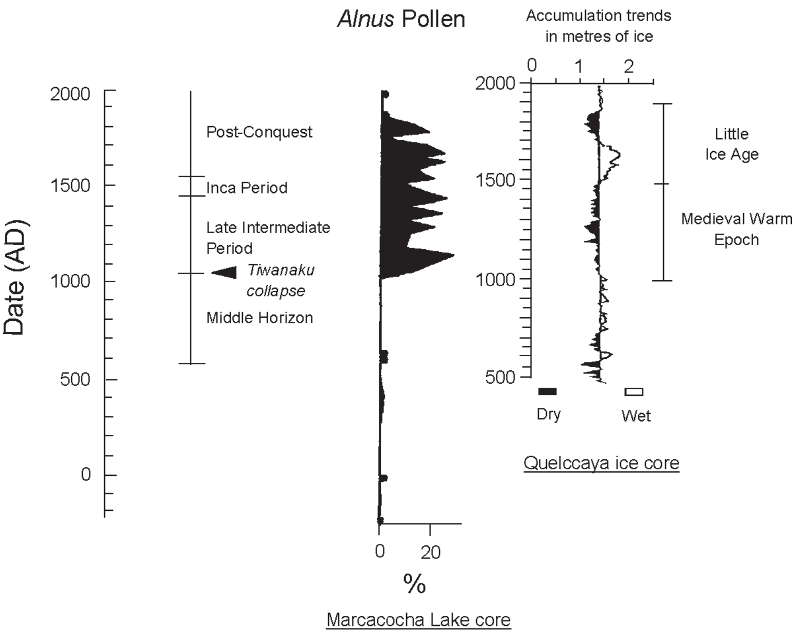


Figure 4. Pollen percentage diagram of aliso (*Alnus*) from Marcacocha and the proxy-precipitation record from the 1500 year Quelccaya ice core (29). The Andean cultural periods shown include the Inca only during their rapid empire expansion. Decadal trends of ice accumulation (precipitation) are shown in the Quelccaya ice core. A drought which possibly caused the Tiwanaku to disappear at AD 1100 occurs about the same time as the aliso rise at Marcacocha, and the initiation of sustained low rainfall in the Quelccaya ice-core record.

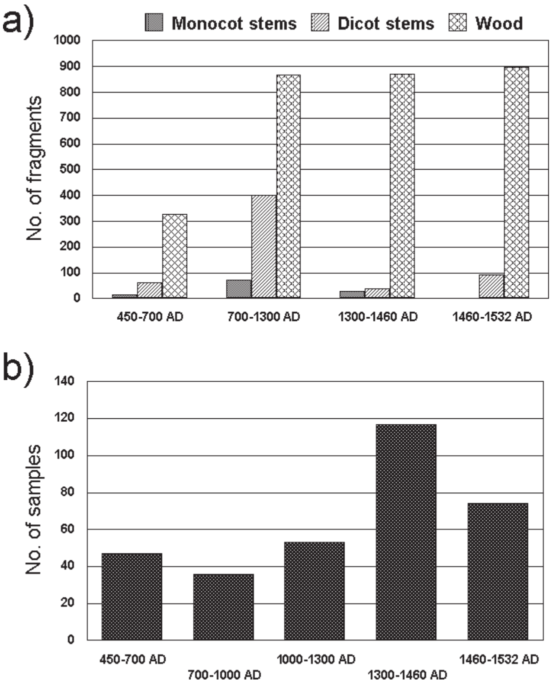


Figure 6a. Changes in relative proportions of fuel use from the stratified site of Pancan between 450–1532 AD (34). b) Number of samples available for analyses of fuel use from Pancan between 450–1532 AD (34). Notice that the time intervals are not equal.

the Inca. This work is already under way on a series of cores collected from lakes and marshy areas in the Cuzco region in February 1997.

ARCHAEOLOGICAL EVIDENCE

The Patacancha Valley, which contains the infilled lake of Marcacocha, is a tributary of the Sacred Valley. During the time of the Inca, the Sacred Valley was one of the most important areas for maize production; it still is today. In close proximity to Marcacocha are a large number of archaeological sites, typical of the Late Intermediate Period (c. AD 1000–1460), suggesting that the local population increased rapidly in the Patacancha Valley at a time corresponding to the increase of aliso pollen in the palaeoecological record (Fig. 2). Aliso lintels for doorways, windows and crossbars have been excavated at Pumamarca fort (7, 30) close to Marcacocha, with radiocarbon dates spanning the Late Intermediate Period up to the Spanish conquest. The fort has three main occupation phases, which Kendall (7) has termed styles 1, 2 and 3. In style 2, imbedded beams of aliso supported upper story floors. It was also noted that c. 1400, the Inca began using chachacomo (*Escallonia resinosa*), a harder wood than aliso, in their buildings.

Figure 5. Catkins and pollen from aliso (*Alnus acuminata*). Pollen are dispersed in large quantities by the wind. Photos: A. Chepstow-Lusty.

There is limited evidence in the archaeological record in the region for a Middle Horizon Occupation (c. AD 700–1000). Towards the end of this interval, however, there is evidence for renewed occupation around the area of Lake Marcacocha, in the strategic position on the ridge top of Hatun Aya Orqo. The large influx of inorganic sediments observed in the Marcacocha core between AD 700-1000 has been interpreted to be the result of soil erosion caused by grazing pressure on a fragile environment with a limited vegetation cover (Fig. 2). Temperatures were beginning to increase after a sustained cold period that had precluded agricultural activity at these altitudes, and Middle Horizon cultures (Tiwanaku/Huari) started to expand up valley (23). This evidence also appears to match the broad archaeological picture of changes in prehistoric fuel use at approximately the Middle Horizon/Late Intermediate boundary, i.e., c. AD 1000 from the stratified site of Pancan in the Mantaro Valley (31–34). Fuel debris was obtained from 6-liter samples of soil using screen and flotation techniques. Three categories were distinguished: wood (mature wood with growth rings clearly distinguishable); stem (immature dicotyledonous wood, twigs or stems); grass (monocotyledonous stems, i.e. from grasses, sedges, etc.). The results showed (Fig. 6a) that mature wood is the dominant category of charred fragments in the samples from all time periods (AD 450–1532). However, there is a major shift from a high proportion of grasses and dicot stems in the Middle Horizon to samples composed almost entirely of mature wood fragments in Late Intermediate and Inca times. At this boundary, there are also changes in the species providing the mature wood. This reinforces the evidence that people were changing their sources of fuel following major tree colonization during a period of climatic warming; people may also have started managing their wood resources. Major demographic changes occurring at c. AD 1300, (34) may be linked to this climatic phenomenon, as population increase led to the growth of fewer, larger fortified hilltop towns.

It is also apparent from this study, that fewer samples, and hence fewer charred fragments were available for analyses from the earlier time intervals, spanning AD 450–1000 (Fig. 6b). This may indicate a limited carrying capacity for people at the time because the climate was too cold. For plant material to be preserved in environments prone to marked seasonal changes, unlike the situation in dry coastal areas, they have to be burnt first or preserved in anaerobic situations. However, only certain plant species are able to survive burning, and preserve their identity. Of the woody taxa, diversity was extremely high with up to 40 taxa in any time period. Of the 12 taxa most commonly present in samples, only 5 could be identified to genus or species level (34). The genus *Polylepis*, including species both planted and wild, was present in all samples. *Polylepis* includes a number of species which are able to survive up to 4300 m today (35) and hence would have coped well with the cooler conditions prior to AD 1000. *Buddleja*, which favors warmer temperatures, was only present in samples taken from towards the end of the Late Intermediate (c. AD 1300). Historical texts suggest *Buddleja* would most likely have been planted. Aliso, however, appears to be absent from the samples. It is not possible to determine whether its absence from the record is due to poor preservation of its wood, or if it was genuinely absent.

In spite of the high abundance of archaeological sites, very few archaeologists have used flotation techniques for obtaining carbonized plant material such as wood remains. This is an efficient method for retrieving plant remains, and gives important ethnobotanical data (36–40) that may otherwise be lost or go unrecorded. Much more work of this nature is required to investigate the major switch to woody fuel from c. 1100 AD.

CONTEMPORARY EVIDENCE

The rural people living in the Andes today probably have a way of life not too dissimilar to that of the Inca people living there more than 400 years ago. Certainly, their relationship with the land and its natural resources would be very much the same. It is possible, therefore, that one can gain some understanding of how the Inca used tree resources from looking at present day practices. A small survey of fuel use in 1985 in the Upper Mantaro valley (34) showed that aliso and *Polylepis* were the most important native trees used for firewood. However, these trees have decreased in value in the last 50 years as they have become replaced by the exotic genus, *Eucalyptus*.

The planting of *Eucalyptus* began in the early part of the 20th century, and it is only relatively recently that native species have been displaced. Harper-Goodspeed, in 1945 (41), described a small village, Cachicadan, east of Trujillo in northern Peru, where aliso supplied most of the fuel used in the village. At that time, wood was obtained from *Eucalyptus* only when trees of *Eucalyptus* died, or when branches were shed.

In the Patacancha Valley, aliso survives today only as scattered individuals along riverbanks and steep ravines, where it is more protected from both humans and grazing animals. There was no evidence of replanting in 1995, and it is certainly being overharvested. Other native trees generally survive if they are protected within the walls of small farmsteads. *Eucalyptus*, though, is managed as a major resource, even on abandoned Inca agricultural terraces. In the adjoining Sacred Valley, Gade (42) notes in 1975 that *Eucalyptus*, or occasionally quishuar or aliso, supply the necessary beams for construction of hut roofs. Wood is also the raw material for most agricultural tools. The wood of the quishuar and chachacomo are highly valued for the *chakitaklla* (foot plough) and pitchforks. Quishuar trees have been planted near huts for this purpose probably since the Inca period. Aliso is also valued for making ploughs and yokes, although the large trees necesssary for their manufacture are today quite rare. In 1975, Gade (42) considered that between 3800–2400 m, 70% of the firewood in the Sacred Valley, was supplied by *Eucalyptus*. After *Eucalyptus*, the next most important firewood species was molle (*Schinus molle*). Other native species are quite uncommon, probably having undergone centuries of cutting. If *Eucalyptus* were not available, native tree species would have greater importance.

DISCUSSION

Prior to AD 1100, the Andes were deforested and suffering from major soil erosion; probably, the land was not very productive. In this paper, we present historical evidence, supported by palaeoecological and archaeological data, that the Inca may have used tree planting as part of their land-management program. Early management of the Andean landscape would have been utilitarian, i.e., to maximize productivity of food and fuel crops. They almost certainly had little concern for biodiversity *per se*. However, the Inca grew many crop species and varieties (5), as well as planting a number of tree species (34) as a consequence, one supposes, of their desire to provide a spectrum of produce and ensure against the vagaries of climate and disease. When the Spanish arrived, they did not find an extensively forested landscape (9). However, the landscape may have been managed with strategic planting of trees, at least on a scale large enough to provide a renewable source of wood for fuel and construction. Planting trees may also have been used to help stabilize mountain soils. The sedimentary record from Marcacocha from c. 1100 AD indicates a marked decline in soil erosion into the lake as techniques such as terracing and possibly tree planting became important components of landscape management. In addition, *Ambrosia*, an indicator of disturbance (25), is no longer common after the appearance of aliso in the palaeoecological record (Fig. 2); a further indication that the Inca were practicing land-management schemes to minimize soil erosion.

It is not yet possible to determine when tree planting first began in the Andes. However, it would not have been an appropriate or efficient strategy in the millenium prior to 1000 AD as the climate was too cold. This climatic evidence for cooling comes not only from the disappearance of agricultural indicators in the Marcacocha sequence (Fig. 2), but from a series of other environmental records from lake cores in the Central Peruvian Andes (24). This is also independently supported by evidence of glacial expansion (43, 44).

Direct evidence for the presence of the Inca, as one of a number of tribes in the Cuzco area, is based on pottery chronology from c. AD 1200 (8). The myth of the founding of Cuzco (the "Navel of the Earth") may have some basis in fact. The legend states that the first Lord Inca arose from Lake Titicaca and travelled north in search of a place to found his city. He carried with him a golden staff that he used to test the ground. When this staff was swallowed up by the earth it was the sign that he had found the place. The climatic change associated with the Medieval Warm Epoch gave rise to a prolonged drought in and around the area of Lake Titicaca (27, 28). The Tiwanaku civilization, which had developed a system of agriculture based on rainfed raised fields, collapsed and its people may have migrated north to find cultivable land. In the Cuzco region, where seasonal rainfall, supplemented by constant meltwater, fed the valleys, agriculture was still possible. Irrigation canals to supply water to stone-built terraces date back to the beginning of the second millenium AD (7).

CONCLUSIONS

Peruvians today find themselves faced with similar environmental problems to those faced by the Inca. The Inca were able to overcome these natural challenges by managing the environment in such a way that it was able to support a population of 30 million people. This was based on a wide range of crops and on a number of tree species, principally *Alnus acuminata* (aliso), *Escallonia* spp (chachacoma), *Polylepis* spp. (q'euna), *Buddleja incana* (quishuar) and *Schinus molle* (molle). That this happened

General view up the Patacancha Valley showing the infilled lake of Marcacocha surrounded by Inca and pre-Inca terraces. The promontory of Juchuy Aya Orqo lies directly behind Marcacocha, projecting from the right side of the valley towards the Patacancha River, which has created a small ravine. Notice how deforested the landscape is. Photo: A. Chepstow-Lusty.

at a time of rising temperatures and reduced precipitation should be investigated further, as it implies efficient management of water resources and protection of watersheds.

Unfortunately, an entirely different approach is being taken today; large-scale silviculture of a single exotic genus, *Eucalyptus*, has been adopted. *Eucalyptus* is a valuable cash crop that is often grown in valley bottoms on good agricultural land. In the past, firewood was largely a communal resource. It is probably no coincidence that the worst destruction of aliso, and presumably other native trees, as indicated from the Marcacocha record, has been during the 20th century (Fig. 2); during this period *Eucalyptus* has progressively come to supply urban markets. Consequently, the value of native trees has markedly declined, as has their management.

Although there is a wealth of practical literature on reforestation with native trees (45–47), efforts to reforest the Andean highlands with native species have been scattered and on a small scale. For example, aliso could be grown nearly everywhere where *Eucalyptus* is now planted. It grows straight and is probably the most productive of Andean tree species, reaching a height of 25 m in only 10 years (35). Due to its multiple uses in the production of wood and in traditional medicine, it has been recommended that this species be used more widely in reforestation projects (48). Planting of aliso in disturbed areas has also been strongly recommended because of its ability to fix nitrogen (49) and so improve soil quality (48). However, it has a rather high water requirement and is more sensitive to low temperatures than either *Polylepis* or *Buddleja*. In order to maintain habitat diversity, it would probably be appropriate to plant a mix of species.

Eucalyptus is favored at present because it is highly productive and its trunks are long and straight, facilitating the planting of large, dense plantations. It grows on degraded and eroded slopes, and besides producing good quality firewood, its leaf litter is highly resinous and can also be burnt. However, its water consumption is extremely large, which is not good in a highly seasonal environment such as the altiplano. The leaves of *Eucalyptus* contain a number of toxic compounds that, once shed from the tree, prevent germination of other plants, and nutrient levels in the soil become depleted (50). In addition, leaves and young branches, unlike those of *Polylepis* and *Buddleja*, are not edible for grazing animals. Planting of monocultures increases pest damage, has negative social effects in terms of ownership, and is hostile to the endemic fauna and flora, including important genetic resources. Wild tuber crops, including various wild potatoes—*Solanum* spp, oca (*Oxalis tuberosa*), mashua (*Tropaeolum tuberosum*) and Ullucu or papalisa (*Ullucus tuberosa*)—have been found in some of the surviving montane forests. Ullucu is widely used in the Andes as a vegetatively propagated tuber and is scarcely known in the wild beyond these forests (35).

Current reforestation projects rarely use native species (51) and some take place directly within native woodland. *Eucalyptus* is not grown solely for supplying Peruvian markets, but is part of the international economy which has mixed benefits. Despite the known ecological disadvantages of *Eucalyptus*, both national and foreign organizations continue to use non-native trees in reforestation. In Peru, for example, a government-supported forestry scheme was initiated in 1997 planting over 100 million *Eucalyptus* trees, mostly in the zone of *Polylepis* and other native species (52).

There would seem to be much to be learnt from ancient land-management practices. Only by providing more information about the extent and efficacy of these programs, can we provide genuine support to the policy makers and nongovernment organizations who are trying to promote the use of native species in modern management programs. The predicted population size for Peru in 2050 is over 42 million (2); presently, it is estimated to be 24 million. Can the resources of the natural environment sustain this rapid population growth? This may be an opportune time to incorporate some of the practices of the Inca into modern industrial agriculture, especially native tree planting, and be rewarded with the social, spiritual, biological and biodiversity benefits.

References and Notes

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53. Keith Bennett is gratefully acknowledged for all his technical expertise and help in numerous ways. Ann Kendall and the Cusichaca Trust archaeological group provided valuable support in visits to Ollantaytambo. Roy Switsur and Andrew Gerrard carried out the radiocarbon dating on the Marcacocha core at the Godwin Laboratory, Cambridge. Tino Aucca Chutas, Alfredo Tupayachi Herrera, Sandra Echegaray and Washington Galiano provided invaluable assistance in Peru. We acknowledge the data for Laguna Paca from the Latin American Database and Barbara Hansen. Steve Boreham provided important technical support, Simon Haberle stimulating discussions and the manuscript was substantially improved by the editing of Charlotte Lusty. The first stage of this work was funded by NERC grants GR9/804 and GR9/02178'A', whilst partial funding for fieldwork has come from the Royal Society, the British Ecological Society and the Montgomery Trust.
54. First submitted 29 Nov. 1999. Accepted for publication after revision 15 March 2000.

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