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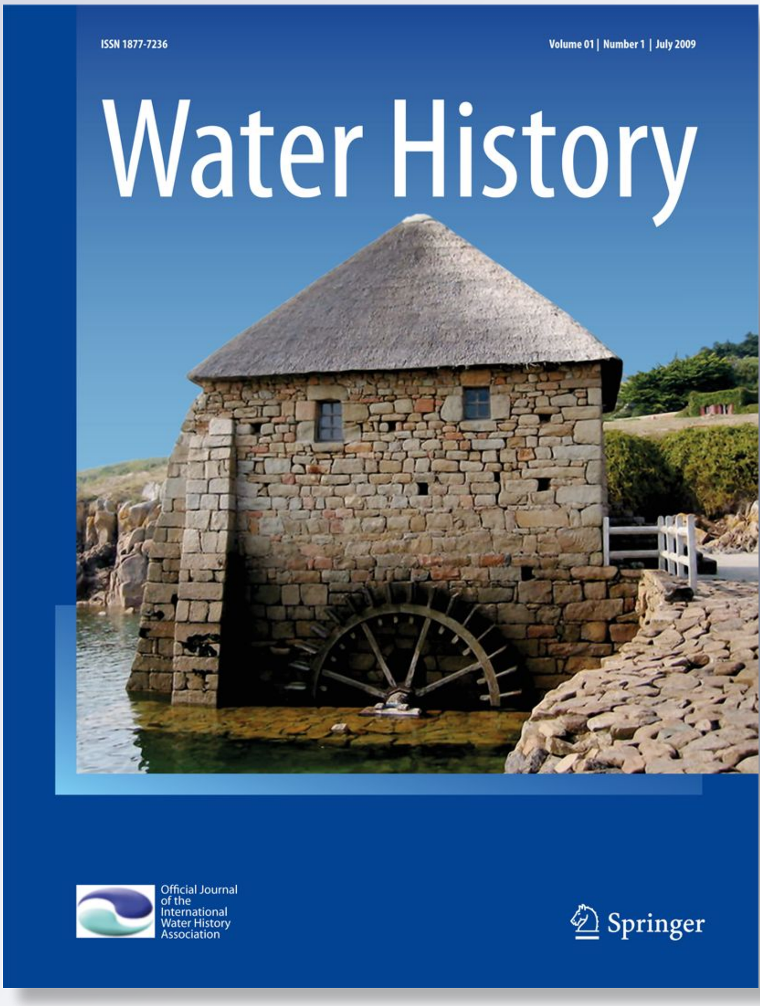

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An inter-continental comparison between the environmental histories of two lake catchment systems in montane environments of France and South West China

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Abstract Inter-continental comparisons of environmental histories can improve understanding of environmental problems and hazards, and suggest possible actions to promote adaptive capacity and resilience in communities. This article presents evidence from two discrete studies incorporating the same integrated interdisciplinary methodology that look at montane foothill environments in France and South West China. The focus of research is on reconstructing the environmental histories of two lake catchment systems, Annecy in Haute-Savoie, France, and Erhai in Yunnan province, China. The initial findings from the comparison point to very similar sequences of an emergent flood problem in the late 17th to early 18th centuries related to upland land-use transformations of different origins that act upon longer-term sequences of environmental change. Flood problems in both catchments have been met by major engineering solutions that, whilst similar to some extent, differ in technical ingenuity. What this comparison makes clear is the importance of micro-variation in environments within these catchments leading to similar, though not the same, adaptive responses to the environment. While it is clear that cultural nuances can be important causes of differences in environmental decision making, particularly in respect to choice and management options, but often the responses tend to be fairly consistent in their approaches to both environmental opportunities and problems.

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Introduction

There has been a call for relevant inter-continental geographical and historical comparisons from geographers, environmental historians and development agencies working in mountain environments (see Jeanneret 2001; Jeanneret et al. 2001). This has been driven to some extent by broader concerns about the impacts of climate change in these sensitive environments (Messerli and Ives 1997, La Sorte and Jetz 2010) and the often under-developed status of the communities living within them. Recent moves to realise trans-national cooperation in the European Alps to achieve sustainability objectives based on long-standing connections between supranational regions [see the work of CIPRA] points to the need to identify such regions in the past, and understand how communities living in these areas adapted to both exogenous and endogenous forces. This also illustrates the point that there may be shared experiences and adaptations amongst mountain communities that transcend national and international boundaries, particularly because these communities are often associated with continuity and adaptability to change (see Netting 1981). Thus, it is feasible that some generalisations about the types of adaptation to these environments may be drawn out on a regional basis (see Dearing 2006). Geertz's (1972) comparison of two traditional irrigation systems in Morocco and the Philippines emphasizes this with an analysis of the technological and cultural differences found in different regional locations that enhances broader understanding of adaptive capacity and community resilience. His comparison was made simpler because these technologies were still extant. The continuity of technology and practice that is a particular feature of mountain environments (Crook 1997) makes these landscapes particularly suited to such comparison. More recently, Subash Chandran and Hughes (2000) have compared sacred groves in the ancient Mediterranean with surviving groves of South India to evaluate the roles of these refugia in maintaining balance between human groups and the ecosystems of which they are part. This emphasizes a further use of comparative analysis which is that it can test general properties of socio-ecological systems, like resilience and vulnerability.

Deciding on what scale these comparative studies should be based is often determined by the type of landscape to be studied. The appropriate scale for comparison varies from different biomes, to regional or localised studies, and ranges from observations of peripatetic to complex systems that can be broad in scope [e.g., technical and cultural transfer] (Vogel and Dux 2010) and even pan-continental [e.g., biomes, populations] (see Smout et al. 2008). A key distinction to be made between studies like Jeanneret et al. (2001) and Smout et al. (2008) is that the former are more coherent and satisfactory. This is because they are based on a planned comparison of the environmental history of two regions, and thus in marked contrast to the papers found in the later publication that are in effect retrospective studies of different works applying different methodologies, and with different research objectives.[1] Jeanneret et al. (2001) based their comparisons of the European and New Zealand Alps on five representative landscapes thus illustrating how inter-continental comparison can only occur where similar traces can be found over congruent bounded landscapes with broadly shared ecosystem characteristics. Work by Harada and Glasby (2000) supports this point as they compare the human impact on the environments

[1] Professor Smout acknowledged this drawback with the 2008 publication in personal communication.

of New Zealand and Japan on the basis of these being two geologically and tectonically similar islands. In contrast, social science comparisons are usually based on population, institutional frameworks and organisational principles, although there are some notable exceptions (see Elvin 2004, 2010; Vogel and Dux 2010). Pawson and Egli (2001) pointed out in respect to the European and Southern Alps that human histories on different continents are very different, with contrasts in respective length of time settled, population, and the types of records that the populations in each environment have left behind. This is where the ideas of Braudel (1980) may become useful in respect to building understanding of the events, conjunctures and the historical *longue durée* in regional research locations, although Elvin (2002) argues that he may have been applying the wrong physical model. This said, the methodology used here is congruent with epistemologies espoused by the recently launched IGBP/PAGES Focus 4 Regional Integration Theme. By building similar frameworks of understanding it allows a comparison of sites that to some extent smoothes out discontinuity and disjunction between the environmental histories of different locations.

Still, the locations where comparative studies of environmental history are possible are limited by the survival of archaeological, documentary, and palaeological records, and indeed to places where these sources are complementary and can be used to remedy temporal discontinuities. Here we compare two such locations in France and China where the same interdisciplinary methodology has been employed. We describe this interdisciplinary methodology and present key results from each study. These are used to assess the adaptive capacity and community resilience in mountainous environments: first, by exploring questions like what, how and when environmental change has occurred; and second, by considering what technological and management solutions for coping [that is adaptive strategies] have emerged that lead to resilience within local communities.

Interdisciplinary methodology

The methodology discussed here was first used in the context of a Leverhulme funded project 'Historical impacts of land use and climate on hydrology in a prealpine landscape' [LEVAN] investigating the environmental history of the lac d'Annecy catchment area in Haute-Savoie, France.[2] This project was both inter- and multi-disciplinary in nature, drawing on techniques and tools from palaeo-science, climatology, environmental history, and landscape evolution modelling. The same methodology was then transferred to another Leverhulme funded project entitled 'Human and climate impacts on water resources in China: learning from the past' [LERCH] centred on the environmental history of the lake Erhai catchment in Yunnan Province, southwest China. The original aim for this project was to provide a basis for understanding the sensitivity of a subtropical hydrological system in China to anticipated impacts from both climate and human activities.

The methodology used in both projects is outlined in Fig. 1. It has five main components: the first identifies the data sources and interdisciplinary tools for collecting data; the second the different types of data analysis; the third involves reconstructing environmental dynamics through examining both extra- and intra-catchment forcings and environmental responses (Dearing 2006); the second and fourth focus on the development and testing of predictive

[2] The Annecy project was run in collaboration with a local consortium (*Syndicat Mixte*) of both professional and lay interests in the Lake known under the acronym of CLIMASILAC see http://www.sila.fr/index.php.

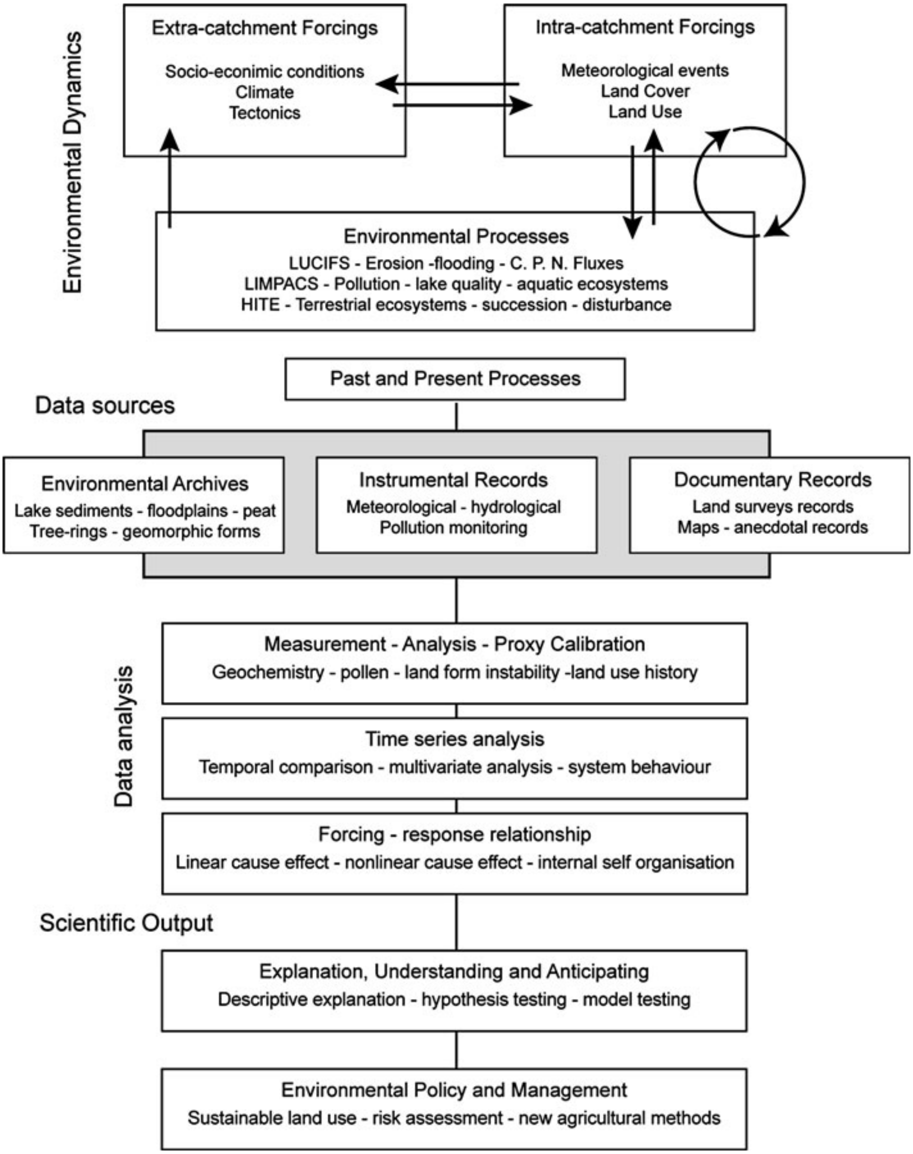

Fig. 1 Transferable lake catchment methodology

models (Welsh et al. 2009),[3] and the fifth takes forward the findings and lessons for environmental policy formulation and environmental management (Dearing et al. 2007, 2008).

The lake catchment provides a useful spatial scale of analysis (cf. Oldfield 1977) because it is congruent with the epistemological needs of the different academic methods used to collect data. The scale of research in both instances was bounded by the physical

[3] To date only the earlier Annecy project has undergone modelling and thus it is not yet possible to compare this component of both projects.

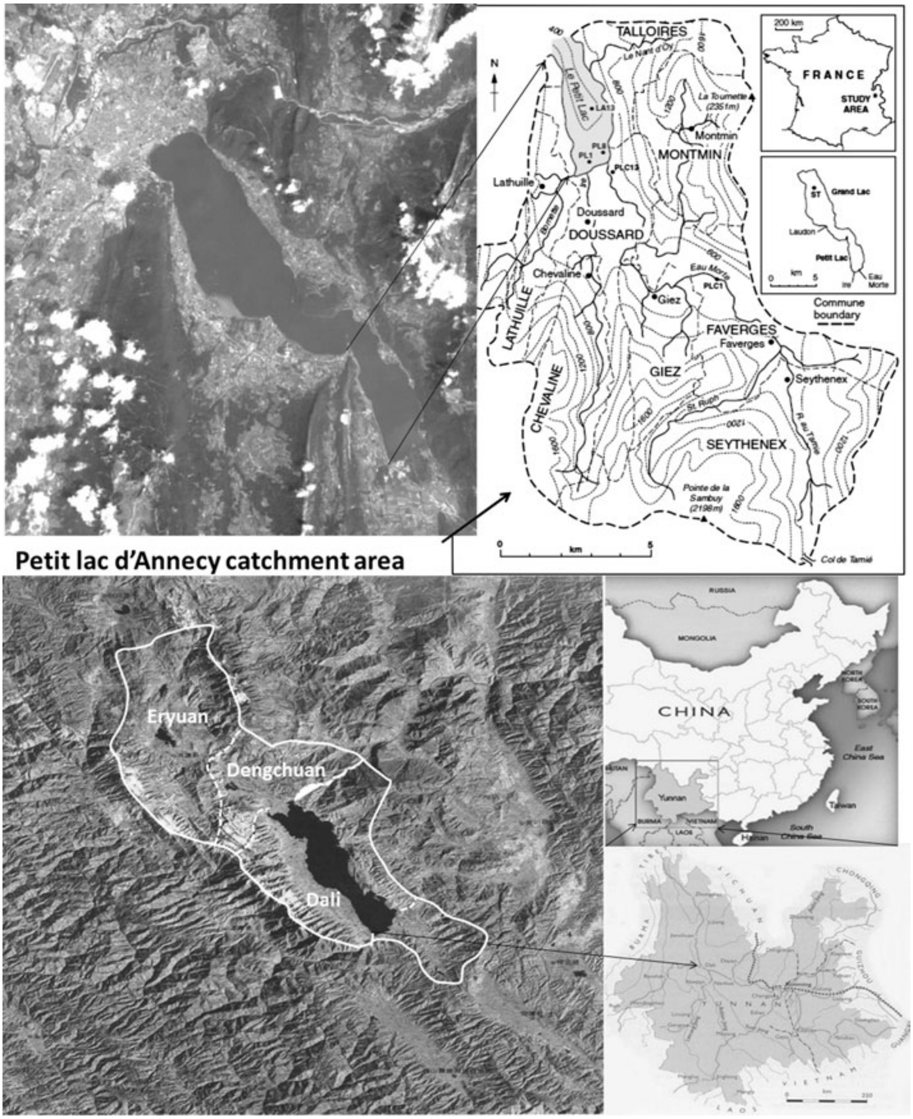

Fig. 2 Petit lac d'Annecy and Erhai catchment areas

parameters of two lake catchment systems (Fig. 2), but micro-variations within and between sub-catchments were also teased out to investigate their contribution to the wider environmental histories (Elvin et al. 2002; Crook et al. 2004).

There are differences between the continuity of different data sets drawn from natural archives and from evidence derived from archaeological, cartographical, and documentary archives. Figure 3 shows how a range of methods, including field survey, palaeoenvironmental stratigraphy, sediment analysis, and dating were applied to each catchment. These facilitated the creation of long continuous time-series data sets based on analyses of lacustrine and alluvial sediments with calibration against modern sediments and landforms.

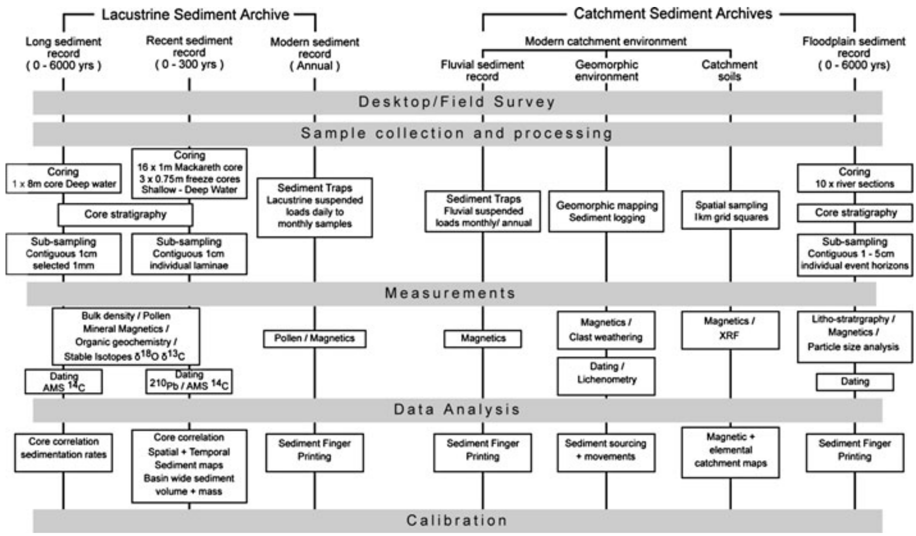

Fig. 3 Methods used to analyse lacustrine and catchment sediment archives

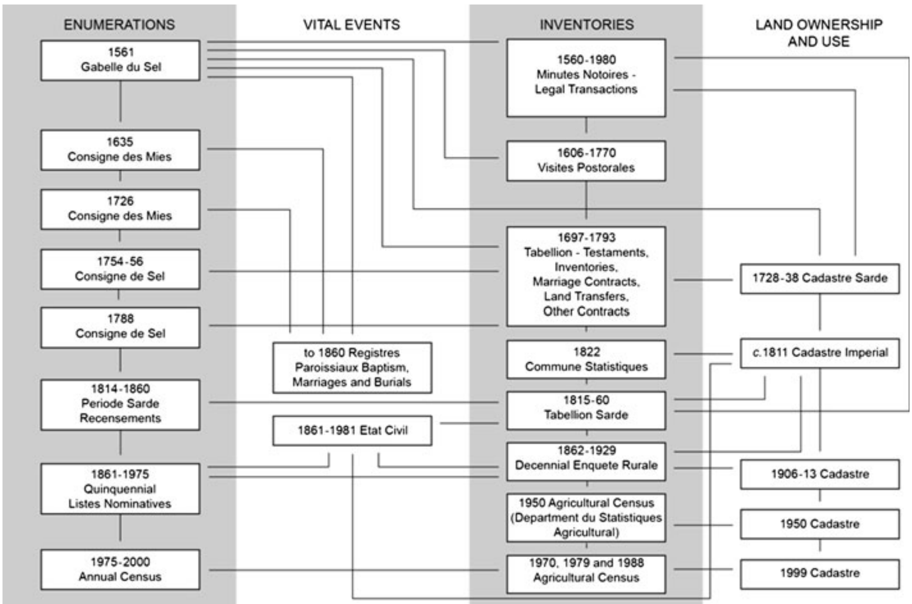

Fig. 4 Documentary archive sources and linkages relating to the Petit lac d'Annecy catchment area

Common analytical techniques applied to sediment analysis included: mineral magnetic properties (Dearing et al. 2001) to define sediment sources and erosional processes (Dearing et al. 2001); particle size as a proxy for detrital sediment input and flood intensity (Foster et al. 2003); pollen analysis as a proxy for catchment and aquatic vegetation (Shen et al. 2006; Dearing et al. 2007); charcoal analysis as a proxy for fire frequency

(Colombaroli et al. 2010); and geochemistry as a proxy for sediment source and industrial activity (Dearing et al. 2007). Sediment chronologies were determined using dating techniques such as 14C, 210Pb, 137Cs, and lichenometry (Foster et al. 2003) with cross-correlation of core records (see Dearing and Jones 2003). In order to overcome discontinuities in documentary sources, linkages were made between different data sets drawn from a list of enumerations, vital event registers, inventories, and land-cover and -use records found in both catchments. Figure 4 demonstrates how this was done for the lac d'Annecy catchment.

For this article, we focus on key research questions related to improving our understanding of the relationship between land use change and flood responses:

- Can similar patterns in flood regimes be found within the two catchments?
- Do the long-term antecedent conditions leading to flooding share any key characteristics?
- Are there any shared adaptations and mitigation strategies for flood hazards in the two catchments?
- How do the above influence our understanding of the vulnerability and resilience of these landscapes?

The physical landscapes

Both the lac d'Annecy [N 45°48; E 6°8] and lake Erhai [N 25°50; E 100°11] catchments are found in mountainous landscapes (Fig. 1). Each site sits inland at the foothills of larger mountains, the Alps and Himalaya. The Annecy catchment is a gateway between the lowlands of north and west Europe and those of Piedmont whilst the Erhai catchment is a gateway between Siam, Tonkin, the Shan States of Myanmar, Tibet, Sichuan, and the lower lands of central China. Erhai is a more elevated site [1974 m] than the lac d'Annecy [446.5 m], but relief is steep at both sites with a maximum altitude of 2254 m at Annecy and 4122 m at Erhai. Thus, the relative relief from plain to summit is very similar in both sites with only a difference of 340.5 m. Both catchments have been affected by tectonics and glaciation processes (Dearing et al. 2001, 2007). The lake at Annecy consists of two basins [the Grand and Petit Lac] surrounded by a catchment comprising Jurassic and Cretaceous strata. Limestone abounds in both catchments, although there are large igneous pockets in the Erhai catchment. Both areas are tectonically active, although Erhai more so than Annecy as it lies on a fault zone; indeed Erhai is the largest fault lake on the western Yunnan Plateau.

The catchment area of Lake Erhai is mainly underlain by sedimentary and metamorphic rocks, specifically carbonate and siliciclastic rocks, and gneisses (Wan et al. 2003), while the Annecy catchment is underlain by Jurassic limestones and marls. In both catchments there is evidence for environmental micro-variation between the north, east, south and west sides of the catchments. In terms of surface areas there are important sub catchments to both lakes to the north of Erhai and the south of Annecy. In the case of Erhai the north of the sub-catchment can be neatly subdivided into the Eryuan and Dengchuan basins (see Fig. 1). There are higher order sub-catchments also feeding into the southern Annecy *cluse* most notably the Ire and St Ruph. Besides this, in both lake catchments the west-side settlement and agriculture has over time been more developed than their respective east sides. Soil types at Annecy vary from thin skeletal rendzinas at high altitude and on steep slopes to fully developed brown earths on lower and flatter terrain where there may be variable thicknesses of glacial tills. Some soils in the Annecy *cluse* are poorly drained and exhibit evidence of gleying (Foster et al. 2003). In the Erhai basin, soil thickness is also strongly related to altitude and slope. Soils are generally free draining and deep with subtropical red soils underlying much of the non-irrigated farmland on the lower slopes around the lake (Yang et al. 2005). Higher altitude soils on metamorphic rocks have poor fertility and tend to support secondary woodland that is dominated today by Pine. The lower valley sides at both sites are susceptible to gullying. The spatial distribution of gullies appears to reflect slope destabilisation due to past phases of land management (Dearing et al. 2007; Foster et al. 2003), which in the modern Annecy landscape determine the position of avalanche tracks and rock chutes.

The majority of the Annecy lake catchment (170 km^2) drains into the smaller Petit lac which is separated from the Grand lac by a submerged bar. Likewise the majority of the Erhai catchment drains into the northern end of the lake. For a fuller comparison of lake-catchment physical parameters and climate/weather patterns see Table 1. There is high energy in the upper tributaries of the Eau Morte River in the Petit lac catchment and also the upper tributaries of the Miju River in the Erhai catchment. Three main tributary rivers, Eau Morte, Ire and Bornette, contribute, respectively, about 42, 15, and 7% of inflowing water to the lac d'Annecy, whereas at Erhai the Miju River is the central drainage channel for the entire northern catchment (see Fig. 1). The major contemporary difference in hydrology lies in the ephemeral nature of the upper Erhai tributaries as opposed to the perennial flow of the northern tributaries in the Petit lac catchment. In both catchments

Table 1 A comparison of lake-catchment physical parameters and climate/weather patterns

	Measure	Lac d'Annecy (Petit lac)	Erhai
Total length of lake	km	14	40
Max width of lake	km	3	8
Catchment area	km^2	251 (170.4)	2322
Lake basin: catchment ratio		9.5 (27.3)	15.5
Lake surface area	km^2	26.5 (6.25)	150
Lake maximum depth	m	64.7	20.2
Lake Volume	km^3	1.12	2.6
Annual variation in lake level	m	1.9	1–2
Alkalinity	pH	7–8	8–8.5
Current water quality issues		Eutrophication	Eutrophication
Weather patterns		Temperate Atlantic weather patterns predominance of westerly cyclones and anticyclones	Subtropical strongly affected by the Indian monsoon
Storms		Convective	Convective
Average annual precipitation	mm	1274.5	1060
Average temperature Range	°C	20.9	36.3
Maximum temperature	°C	21.5	34
Minimum temperature	°C	−0.4	−2.3
Mean average temperature	°C	10.3	15.1
Potential evaporation		nd	1970

Sources: Brenner et al. (1992), Dearing et al. (2001, 2007, 2008), Druart and Pelletier (1998), Foster et al. (2003), Huang et al. (2011), Wan et al. (1988, 2003, 1996) stream-flow slows as it passes through substantial flood plains that are important both to housing and agriculture. The Miju is different from the Eau Morte in that its bed now sits above the surrounding land behind manmade embankments built up over several centuries. The Erhai catchment contains small lakes in the upper parts of the catchment and a substantial manmade reservoir. The former were more extensive in earlier times [i.e., Ming or Qing Dynasty] than at present, but land drainage has reclaimed this land (Elvin et al. 2002). Land drainage has also been important in converting marshy land into farmland in the Annecy Petit lac catchment. This was a process probably started on a large scale in Gallo-Roman times (Boisonnade 1937). The main tributaries to both lakes, the Eau Morte and Miju River, have been dramatically canalised and straightened with flow rates altered. In both the stream-flow is lazy and depositional which has led to the creation of large deltas into the respective lakes that have provided repositories for environmental signals in the sediment deposits (see Figs. 6 and 7 for results). One aspect of hydraulic control missing from the Annecy catchment that is found throughout the Erhai catchment is irrigation, although in both catchments hydraulic power has been used to drive proto-industrial and industrial machinery (Crook et al. 2008).

Climate

It is clear that at times both climate and weather patterns have impacted upon human activity in the two catchments. Our ability to reconstruct localised patterns of weather and climate impacts are limited by the availability of local sources even though these are certainly in relative terms better for the Annecy catchment than for many other parts of Europe (see Nicolas 1978; Crook et al. 2002). Thus, greater emphasis has been placed on independent regional climate signals (Chen et al. 2000; Haas et al. 1998: Wang et al. 2005; Vinther et al. 2006; Ge et al. 2008; Zhang et al. 2008) used alongside local weather records (Crook et al. 2002) to try and compare phases of climate change in the two catchments (Fig. 5). The two catchments are very different in terms of climate patterns with Annecy impacted by temperate Atlantic weather patterns and a predominance of westerly cyclones and anticyclones whilst the Erhai catchment is subtropical and strongly affected by Indian monsoon weather patterns. Both catchment areas are prone to summer convective storms that have proved important is mobilising sediments. Perhaps the greatest difference in the two catchments caused by climate is the need for seasonal irrigation in the Erhai catchment and drainage of excess water in the Annecy catchment. In Erhai periods of water scarcity have contributed in part to periods of drought that have impacted on human and livestock population figures.

Population and development in the catchments

Demographic expansion in both catchments is hard to reconstruct because of the scarcity and poor survival of census and enumeration sources for any time before the medieval period. It is possible to begin to estimate population expansion and vacillation in the commune of Montmin in the Petit lac d'Annecy catchment (see Crook et al. 2004) with a reasonable amount of certainty because of the availability of quantifiable and comparable vital event registers (Jones 1987) and then infer these trends to the wider Petit Lac catchment until the population becomes easier to estimate after the enumerations of the 1561 Gabelle du Sel. In the case of Erhai it is far more difficult to quantify with any

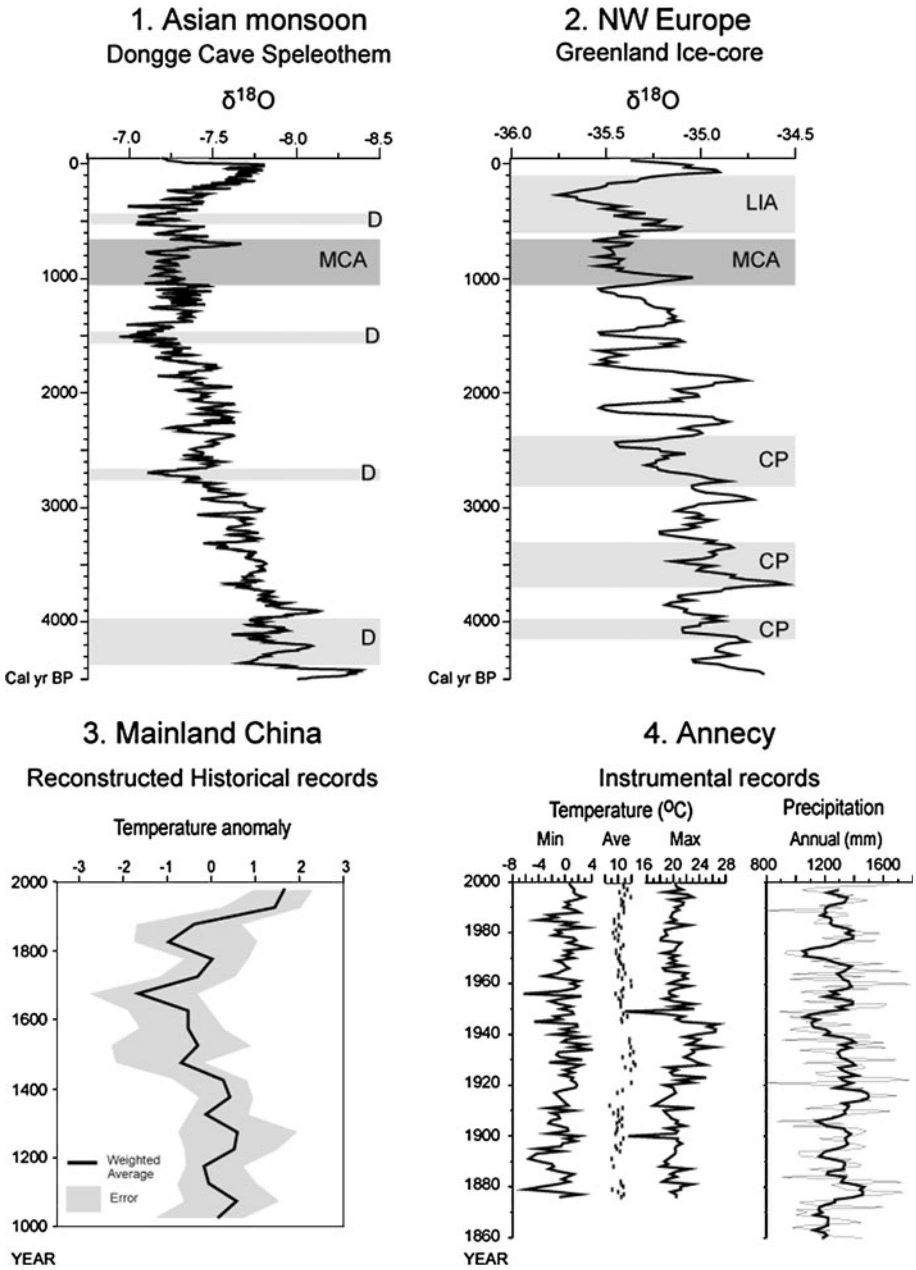

Fig. 5 Range of palaeoclimate records used in the two studies at Erhai and Annecy. *1* The Dongge Cave speleothem record (5 year average) provides a high-resolution record of declining monsoonal intensity over the late Holocene. The record is characterised by several centennial scale droughts (*D*). Redrawn form Wang et al. (2005). *2* Greenland Ice Core Chronology 2005 (GICC05) 5 year average from Vinther et al. (2006). Three European cool events recorded in glacial and tree lines records from the European Alps are marked (Haas et al. 1998) along with the Medieval climatic anomaly (MLA) and the Little Ice Age (LIA). The identification of the Little Ice Age in Asian records is still open to debate. *3* Temperature anomalies in China are re-drawn from Ge et al. (2008). *4* Temperature and precipitation records for Annecy redrawn from Nicolas (1978) and Crook et al. (2002)

exactitude the catchment population for any particular period in time because of the lack of document survival and the scant sources available to us. There are 19th century records of population in separate prefectures contained within the Erhai catchment, but not the whole catchment. These at least provide a general feeling for the population trajectory. What is possible is to gleam from historical accounts the general trajectory of the catchment population and point to periods of both growth and decline as a result of political vacillation and warfare recorded in various gazetteers. These records are set alongside the demographic impacts of natural disasters contained within accounts of auspicious and uncanny events. Table 2 shows a comparison of the key demographic and development phases in the two catchments as partial explanation for environmental change in the two catchment areas described in the results section.

Results

The following section provides an interpretation of the key results from a selection of the techniques used to analyse both lacustrine and catchment sediments in the principal catchment areas, the Petit lac catchment (Fig. 6) and the northern Erhai/Dengchuan catchment (Fig. 7). The time covered by the comparison is 1000 BCE to present. This is then followed by a comparison of the historical flood records for both catchment areas to show the relationship between different environmental processes operating over long, medium, and short timescales.

Figure 6 provides results for the Annecy Petit lac catchment. Peaks in non- arboreal pollen [NAP] and soil organic matter point to a period of agricultural expansion in the catchment that is thought to reflect the creation of Iron Age alpages and subsequent upland clearances in what were quite favourable climate conditions. These points to the creation of alpages in this part of the pre-Alps occurring somewhat later than in contiguous parts of the Alps (Carrier 1932). A major development in open land [NAP], starting around the change of eras BCE/CE and peaking around 800 CE, correlates well with two significant peaks in soil organic content. The agricultural indicators of *Juglans* and cereals significantly increase in a slightly delayed response to the aforementioned proxy signals which suggests that clearances on the floodplain and surrounding slopes were in line with periods of mainly monastic expansion of agricultural granges (Benedictine and Cistercian), although these records suggest that earlier assartment and (re)clearance by secular landlords may have created the preconditions for this expansion. A peak in the mobilisation of low- to mid-altitude valley soils supports this idea of agricultural expansion. What follows in the historical record is a retraction of the agricultural system in line with population declines as a result of protracted warfare and epidemics. A second period of agricultural expansion comes around 1500 CE close to a known apogee in human and livestock populations in the catchment, although interestingly not during a period of particularly favourable climate conditions. More latterly, farmers in upland communities like Montmin and the upper zones of floodplain communes were able to exploit favourable weather patterns (see Crook et al. 2002) that extended the growing season at higher altitudes at the beginning of the 19th century (see Crook et al. 2004). The signal in high-altitude valley soils [HIRM G], generally noisy for the first two millenniums, shows a steady increase until peaking in the 19th century alongside a rapid and sharp increase in the mobilisation of low- to mid-altitude soils. The record for erosion in the Petit lac catchment points to a steady and escalating problem that spans the whole period of analysis and thus points to a key environmental threshold being crossed at the start of the record.

Table 2 Key demographic and development phases in the two catchments

Timeline	Annecy		Erhai	
	Population	Developments	Population	Developments/evidence
~2000 BCE	Isolated settlement around the lake	Bronze age clearance of alpages (1700–900 BCE)		Some agricultural settlement of lake shores and higher-level lakeside slopes
Roman period	Population growth	Establishment of Faverges and Seythenex and granges—some drainage of floodplain	Han expansion	Introduction of Chinese style irrigation technology onto floodplains + 18 streams
8th century CE			738–902 CE Trans-boundary trading system contributes to growth in population	Establishment of Nanzhao Kingdom—capital on western shore & shortlived Dengtan Kingdom in the northern catchment
879–1132 CE	Start of substantial population increase	Monastic granges of Talloires and Tamie established + new upland commune of Montmin	937–1253 CE suggestive of population increase	Dali Kingdom First evidence of substantial irrigation system in operation
13th century			Population healthy, densely populated	Mongol conquest
Mid to late 14th century	Population reduction followed by	War and Plague	Settlement of Ming army veterans	Ming conquest; partial demolition of local culture
15th century	PLC population recovery 1413 = 2289 1443 = 2506 1481 = 2614			First surviving water-control regulations competition for scarce water evident
Early 16th century	Population recovery PLC 1516 = 3850			
Mid 16th century	Population peak in 1561 = 5291	Gabelle du Sel		

Table 2 continued

Timeline	Annecy		Erhai	
	Population	Developments	Population	Developments/evidence
Late 17th century		Malthusian checks in the 17th to late 18th century (plague, poor harvests, famines, wars)	Population increase	Major deforestation in the east of the catchment + introduction of new irrigation quotas
Early to mid 18th century	1754 PLC population = 4265		Luoluo villages on slopes above Baihan dry gorge	Hillslope land-opening intensifies sediment burden in Miju
Early to mid 19th century	1866 PLC population = 7011		Possible Qing population maxim Dali prefecture 1820 = 748 k; 1830 = 802 k	1816 Major flood resulted in a massive loss of life
Late 19th century	1896 PLC population = 5817		Large population decline	Suppression of Mohammedan rebellion following pestilence
Early 20th century	Population nadir 1911 PLC population = 4911	Rapid outmigration—uncompetitive agriculture	1919–1925 Large population decline	Influenza pandemic and massive earthquake damage
Mid to late 20th century	PLC population recovery 1954 = 5959 1975 = 8255 1999 = 11129		Population recovery 1982 Xiaguan city 120 k, Dali county 259 k, Eryuan county 263 k, Binchuan 270 k	People's Republic of China historic population maximum

Fig. 6 Petit lac d'Annecy results

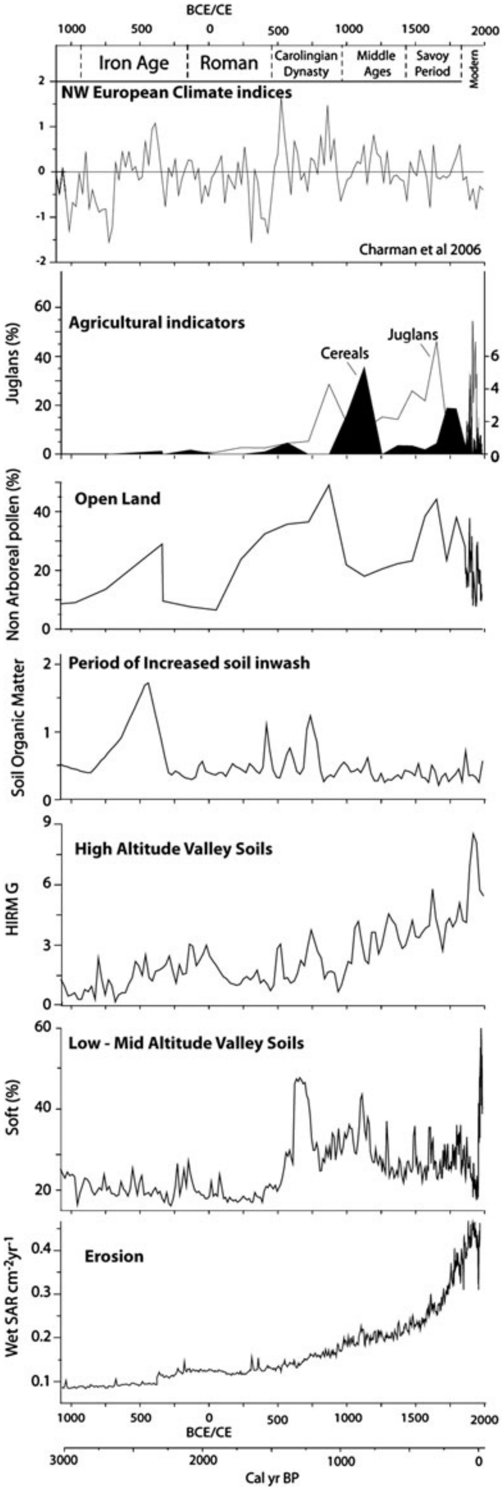

Fig. 7 Erhai results

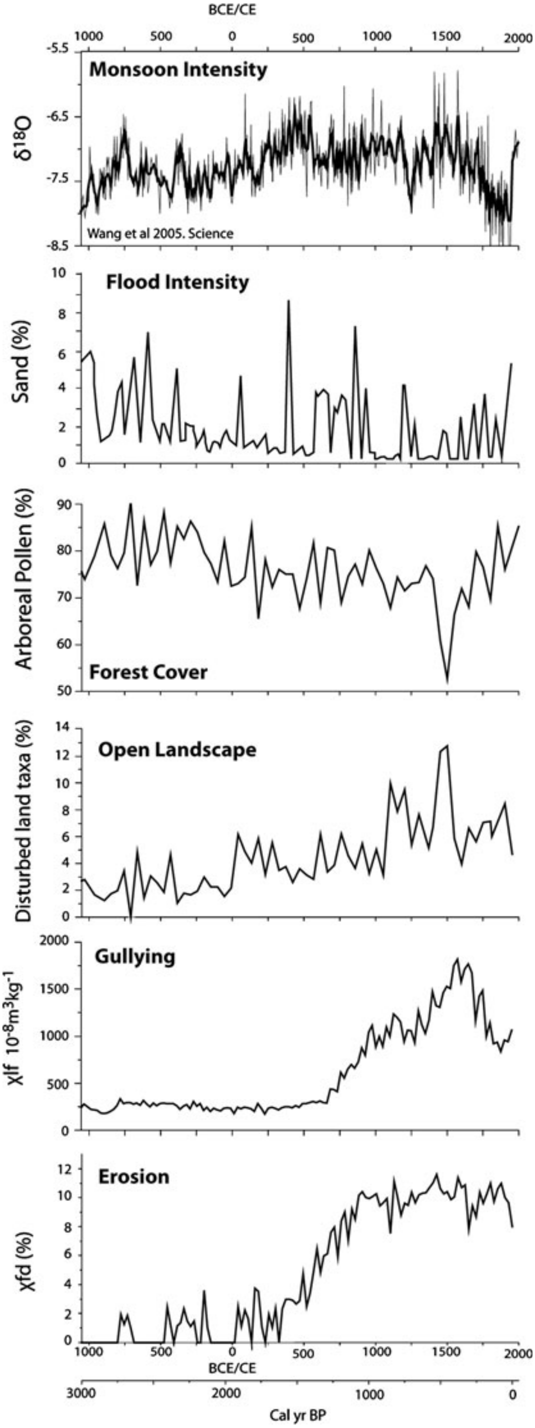

Figure 7 shows results from the Erhai catchment. There are some early signs of erosion during the Bronze Age period but this record does not become consistent until the start of the CE. The earlier record of erosion in the first millennium BCE to some extent correlates with opening up of the landscape. Interestingly the flood-intensity record is quite high for this period which suggests that initial destabilisation of landscape increases vulnerability to flooding. A threshold for erosion seems to have been crossed as a result of the introduction of Han [$\sim$206BCE-220CE] irrigation technology into the catchment although the lag time to further landscape disturbance proxies suggests some stability of landscape occurred as a result of this technological innovation. Paradoxically a flood intensity apex is reached during this period. During the later part of the Tang Dynasty a key environmental threshold was crossed with the triggering of gullying becoming a long-term and growing problem, particularly during the Nanzhao and Dali Kingdom, when the landscape became more open and flood-intensity reached a new peak. The late Ming and early Qing dynasties are particularly important because they mark a massive decline, and nadir, in arboreal pollen, and an opening up of landscape. Thus, all proxy records for landscape disturbance point to this period having been one of quite clear environmental crisis. Pollen records and a decline in disturbed land taxa and gullying suggest that subsequently there has been some recovery.

The historical flood records shown in Fig. 8 are slightly at odds with each other because the Petit lac d'Annecy records are subdivided into the records of first-order tributary streams, the Eau Morte (EM), Ire (I), Bornette, St Ruph (St.R), and Montmin (M). In contrast the Erhai flood record only relates to the main tributary river, the Miju, that debouches into the northern end of the lake from the Dengchuan Basin.[4] Unfortunately, to date there are not extensive sub-catchment records of flooding in the main (northern) Erhai catchment, although there are good records for the famous 18 streams on the Western Shore (see Elvin et al. 2002). In the Petit lac d'Annecy a general problem of flooding was officially recognised in Savoy as early as 1729 with the issuing of general legislation, which sought to control the on-going problem of continual and frequent flooding in torrents (Mougin 1914). This problem extended to the catchment with major corrective works (e.g., dyking) carried out on the Eau Morte in the vicinity of Faverges after various floods of the St Ruph between1734 and1744. Hydraulic engineering remedies were already a feature of the Petit lac d'Annecy catchment at this time and the Ire, which suffered from severe flooding in the 1730–1750s was referred to as one of the most formidable torrents in the province according to a deliberation of the three parishes of Doussard, Chevalines and Lathuile in 1750 (Crook et al. 2002). In the Erhai catchment the Miju river was already dyked by about CE 1425, and by CE 1550 there was the need for regular maintenance. Xu Xiake's (Elvin and Crook 2003; Elvin 2005) accounts suggest that there were no noticeable hydrological difficulties around CE 1650.

The sediment pollen record suggests that around this time the maximum extent of agricultural land with peak topsoil erosion was approaching, and it is suggested that the channel infilling on the Miju recorded after about CE 1700 was driven by accelerated erosion (Dearing et al. 2007). The continued rise in gully and basalt sediments reaching peaks, slightly later than the peak extent of agriculture, at *400–300 cal year BP and *250 cal year BP, respectively, means that the number, length, or depth of gullies in the catchment were also increasing most notably in the Baihan dry gorge where a major diversion bund had been constructed to prevent blockage to the entrance of Putuo gorge.

[4] The Miju flood record only records floods in the lower drainage basin of the Miju, there is no concomitant flood record for the upper Eryuan Basin found to date.

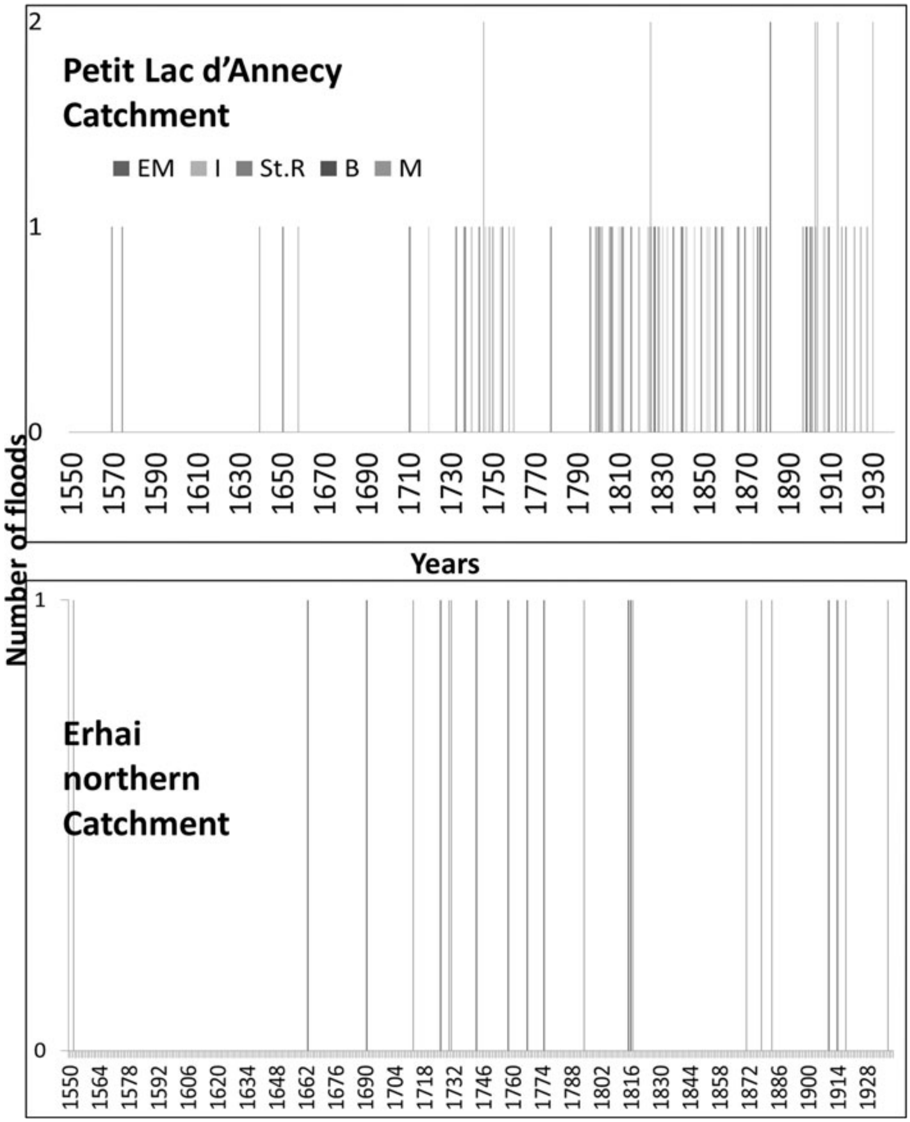

Fig. 8 Flood histories from the Petit lac d'Annecy and Erhai catchments

Between CE 1713 and CE 1817 there were 13 documented river breaches during the late-summer/autumn monsoonal floods, timing that is consistent with the sediment record of high flood maxima trend. Thus, it appears that major gully growth, lagging behind the timings of agricultural expansion by a century or so, is a key factor in explaining the serious flooding on the Miju river. In relation to the latter the central part of the Erhai catchment during the early Ming period was already experiencing a strategic seasonal shortage of water, and conflict within the population over a scarce resource. Military colonists were the group most under pressure and there was the need for continual government intervention to keep the peace. More recently, inclement weather with heavy rains sometimes associated with the early arrival of the monsoon led to flooding throughout the

Erhai catchment in 1871, 1878, 1883, 1910, 1914, 1918, and 1938 (Rocher 1879:158; GF 23/9/14). Those floods recorded in the early 20th century sequentially represent the worst floods on record in the province, which indicates a growing severity in flooding.

The delta of the Miju River was activated and grew rapidly from the Late Ming period as a result of anthropogenic changes to the hydrology and sediment load stemming from upstream problems relating to Putuo Gorge and downstream flooding (Elvin et al. 2002; Elvin and Crook 2003; Elvin 2005). It is interesting to note that the prelude to flood problems in the Annecy Petit lac catchment also occurred spatially at the inflexion between the upper catchment of the St Ruph River and the Eau Morte. This problem was a major issue at the beginning of the 18th Century (Mougin 1914) about 100 years later than that in the Erhai catchment.

Discussion

The discussion takes the form of dealing in sub-sections with systematic similarities and contrasts between the environmental histories of both catchments. In doing so it also examines similar and contrasting social responses to environmental stress and where possible suggests inductive hypotheses for human-environment interactions that lead to both environmental crisis and stability.

Early settlement

In both lake catchment environmental histories it is unquestionable that both sets of inhabitants have fought to gain authority over landscape by regulating natural processes and harvesting resources first through forage and hunting, and then farming. Life switched early in these histories from determinism to control. It has been shown that the Annecy catchment became a 'human-affected environment' ~5000 cal year BP (Dearing et al. 2001). This probably represents the dispersion of the population away from around the lake edge to establish sedentary agricultural units on alluvial fans and on the gentler slopes of the Laudon and St Ruph valleys. In the Erhai catchment the sediment records show a 'human-affected environment' much earlier than in the Annecy catchment at ~7,000–6,200 cal year BP (Dearing et al. 2007). In marked contrast to the early human perturbations of the Annecy catchment the peopling of the landscape of Erhai probably represents the dispersion of the population away from established sedentary agricultural units on alluvial fans to the more inhospitable margins of the lake and the valleys (Elvin, unpublished). In both instances this perhaps signifies the end of a 'nature dominated' phase (Messerli et al. 2000) where society could cause significant modification of the landscape but was still vulnerable to the main risks of drought [though only in Erhai] and flood [though the evidence for climate determinism is weak].

Major settlements in both locations have developed on or near the edges of the lake shore. Annecy at the outflow of the lake and Dali slightly elevated on the western shore.[5] In both catchments there are also important second-order settlements that have important environmental narratives that play out in the upper reaches of both catchments, these being Dengchuan and Eryuan in the Erhai catchment and Faverges in the Petit lac d'Annecy

[5] Since the 19th century Xiaguan, located at the outflow of the lake, has become the major settlement in the Erhai catchment. The towns at Annecy and Xiaguan mirror each other in that they command the location next to the lake's outflow and have their origins as a cross roads for trade.

Table 3 Periods of autonomous control in the history of the Lake Annecy and Lake Erhai catchments

Location	Period	Occupiers/rulers
Annecy	1742–1748	Spanish
	1754–1792	Sardinian
	1815–1860	Sardinian
Erhai	652–902	Nanzhao
	937–1253	Dali Kingdom
	1855–1873	Mohammedan

catchment. However, they remain secondary to the influence of the towns of Annecy and Dali that have at times both acted as regional military and political centres and also become capitals of duchies and principalities. In both cases this has led to an intermittent and punctuated political and economic history (Table 3). Strategic regional power was also expressed on the transalpine passes in both catchments. These were clearly easy places to control and extract taxes from the movement of livestock, people, chattels, and goods. As such the control of these movements has been an important way of raising revenue for local communities otherwise reliant on subsistence farming. In both locations a cross-boundaries functional system (Prasertkul 1989) has operated, and a link has been made between the catchment area and other distant locations that at times have reverberated in both positive and negative ways on these environments, as is reflected in the sedimentary records of both catchments. In Annecy, inhabitants crippled by taxes, without labour in winter and gaining only a meagre living from the land, often chose to practise either seasonal or temporary migration to outlying areas to gain employment in the burgeoning towns and cities of the lowlands. Families and households were maintained by these people sending back remittances to consolidate land holdings (Siddle 1986). The history of Erhai catchment inhabitants is likewise marked with similar tales of human resilience and adaptability to a limited living gained from the land. Through this livelihood strategy people in both catchments maintained a higher relative standard of living than that found in their respective contiguous regions.

Early technology

A major difference in the environmental histories between the two catchments arises from the introduction of a planned reticulated paddy field system used in conjunction with irrigated farming on the Erhai catchment plain at ~2000 cal year BP (Elvin et al. 2002). This introduction of gravity-fed irrigation is associated with a trend of weakening monsoon intensity, increasing numbers of centennial scale dry phases, and population growth. It represents an agrarian society in transition, using technological innovation to raise carrying capacities without increasing greatly its vulnerability to drought or flood. In the Annecy catchment drought was a rarity and there was no recourse to the use of irrigation, but rather drainage on floodplains was a more pressing issue that started to be responded to at roughly the same time (Boisonnade 1937).

Exploitation of hillslopes

The next major phase of human perturbation in both catchments was the point-surface erosion and gullying caused by increased exploitation of mountain slopes. In the Annecy catchment this was driven by the inhabitants of relatively recently established [*c.* 11th century] upland communes like Montmin who wished to exploit favorable growing conditions and extend agriculture to its absolute margins in the Petit lac d'Annecy at the end of the 18th and early 19th centuries (Crook et al. 2004). In contrast the exploitation of mountain slopes in the Erhai catchment was conducted by minority groups forced onto these slopes by unfavorable political conditions on the plain ~1600 cal year BP. Loosely put this amounted to the concurrence of natural population growth, inward migration and increased metal extraction brought about by the rise of Nanzhao/Dali Kingdoms as an autonomous polity involved in what is now referred to trade in a cross-boundaries functional system (Prasertkul 1989). A further contrast between the two regions lies in the exploitation of artificial pasture at altitude. A large part of the surface area of the Annecy catchment is characterised by artificially created upland pasture. No such surface area exists in the Erhai catchment, although there are substantial and under-utilised natural pastures.

Terracing

It is an anthropogenic feature in both catchments. It is, however, a more extreme feature of the Annecy catchment where space is more limited and terraces are built on much steeper slopes. The present terracing in the Erhai catchment is mainly a feature of rice-paddy cultivation and although more extensive than in Annecy mainly occupies the gentle and often artificially produced slopes of the Miju floodplain. Both sets of terracing were introduced from an early age probably about one millennium ago in Annecy and two millennia ago [Han Dynasty] in Erhai (Elvin et al. 2002). In the Erhai catchment mid-slope terracing probably first occurred with the movement of the Loulou onto higher ground in locations like Tower Mountain (see Elvin et al. 2002) and more recently has been associated with the push for grain during Mao Zedong's Cultural Revolution (Shapiro 2001; Elvin 2009) and also associated with much more recent [1980s] attempts to control erosion and support reforestation (see Yan et al. 2005). This desire for the intensification of grain production was probably also the spur for mid-slope terracing in the Annecy catchment.

Flooding

In the Petit lac d'Annecy catchment the main threat of flooding appears to have come from high-magnitude low-frequency flooding driven by clear-felling of the upper slopes of the Ire catchment and to a lesser extent the Montmin and St Ruph sub-catchments. Demands on wood in the Petit lac catchment were often extraneous and fleeting as a result of large military movements[6] in the catchment, and more concerted and intense as a result of the concentrated demand for wood by the large lignite mine opened at Entrevernes in the late 18th century (Crook et al. 2002). Often these problems were exacerbated by ineffective technical responses in relation to hydraulic engineering programmes designed to prevent flooding in the tributary streams of the Ire, Bornette, and St Ruph rivers. In the Erhai catchment the main threat of flooding to the region was high-magnitude low-frequency flooding of the agricultural plain and low terraces, which was exacerbated by: continued use of high-altitude and steep slopes for grazing and cultivation that generated high runoff from unprotected slopes and maintained active gully systems, particularly in the northern basins; reduction or poor maintenance of paddy-field systems, engineered flood defences, river channels and terraces; and the increased intensity of the summer monsoon. The speed of development of the flooding in the Miju catchment perhaps reflects a difference in

[6] Eg: Spanish troops moved through the catchment in the early part of the 18th century.

resistance to slippage and erosion on cultivated steep slopes in sub-tropical soils as opposed to Alpine soils. The mass mobilisation of workforces to conduct public works was a feature of both catchments. In the Annecy catchment this tended to occur on a small-scale (*c*. 30–40 men and women) and a community basis in the form of annual *corvée* obligations to landlords or communal councils. In the Erhai catchment the obligation often arose as a result of government orders at the department level, which resulted in annual large-scale (*c*. 30,000 men) mass mobilisations of labour for dredging and maintenance of the Baihan dry dyke. Typically this type of mass movement was associated with drainage and anti-flooding campaigns. A key feature of the flood regimes of both catchments is that human activities in the upper catchment areas have in a major part contributed to a flood problem in the lower parts of the catchments. This has created a legacy of flood control in the lower communities inherited from upper parts of the catchment. In the Eryuan basin the building of the Baihan dry dyke prevented blockage to the entrance of Putuo gorge that had at times resulted in the backing up of floodwaters in the upper basin of the Miju (Elvin et al. 2002). To a much lesser extent corrections to the St Ruph/Eau Morte river channels in the Annecy Petit lac catchment also transferred flood problems to downstream communities. These downstream communities have responded with hydraulic engineering solutions and increasing bureaucratic control of water extraction and diversion that have over time become refined and improved. It is suggested as a hypothesis that the improvement in the situation regarding floods in the lower parts of lake catchments with a dominant agricultural character to a large extent are dependent on a concomitant reduction in the exploitation of upper slopes and greater stability of upland landscape either as a result of the contraction of agricultural areas [potentially associated with re-naturalisation] and/or the introduction of successful soil conservation strategies.

Commerce

The pressures on the environment in the Erhai catchment and nearby areas in the 18th century were in good measure created not just by the expansion of the local population, but also by the increasing degree to which the rural economy was being commercialized. Both of these themes can be seen in the official promulgation on inscribed stone tablets of various measures to protect the forests, as well as limiting erosion and preserving good-quality water supply that began to be issued in the later part of the 18th century. An example from Jianchuan in 1783, whose preamble mentions the rise of various local wood products manufactures, and lays down seven prohibitions on the use of public mountain lands.[7] These include bans on both private occupation of these area and the encroachment onto them by village communities, on the cutting by quarry workers of living trees near sources of water, on any burning of the hillsides, on felling young trees, on pulling out trees by their roots, and, perhaps most significantly, on selling any timber taken from them (Duan and Zhang 2000). The Annecy catchment also witnessed growing commercialisation of landscape that peaked a century later than that found at Erhai with the introduction of *fruitiers* in response to a rationalisation and modernisation of the milk industry and silviculture (Crook et al. 2002, 2004). This increasing specialisation of landscape went hand in hand with a growing number of communal bans and promulgations particularly related to restricting access to woodlands for goats (see Blatter 2009 and Siddle 2009).

[7] The understanding of the translated words for 'use of' and 'public mountain lands' is tentative.

Carrying capacities

Pre-20th century livelihoods in both catchments have been typically based around subsistence agriculture; however, what this has meant in relative terms highlights some of the dissimilarities in agricultural systems between the two locations. The agricultural landscape of the Annecy catchment contains a far more heterogeneous adaptation to land use and crop choice than that of the Erhai catchment, where rice-growing dominates agriculture,[8] which is centred solely on the plain. However, crop and seed yields obtained by farmers in the Annecy catchment were and still are substantially below that obtained in the Erhai catchment (George Forrest Collection). In the latter the use of chemical fertiliser became very popular in the 1970s. The use of draught animals was more common in the European system, whereas in the Chinese system people carried out most ploughing and hoeing. This allowed for the much higher densities of people to live in the Erhai catchment than those found in the Petit lac d'Annecy. The major draft animals in Annecy were oxen, now replaced by mechanisation; in Erhai this technological transfer is less marked and buffalo remain popular draught animals. Both areas seem to have been important historically as locations where horse-markets took place, although mules and donkeys were preferred equine livestock. Cattle, once important in the Erhai catchment [8–14th centuries CE], are now less so. In the Annecy catchment there is evidence for periods of decline in soil fertility (see Crook et al. 2004), but in contrast there is little evidence for this in the Erhai catchment even though in both catchments the primary addition to soil was night soil and animal manure, until the late introduction of chemical fertilizers in Erhai and nitrogen-fixing leguminous and ley crops in the Annecy catchment in the early 20th century. With much larger numbers of livestock in Annecy than Erhai the explanation for such better crop returns in the Erhai catchment must lie in irrigation and the sediments deposited during the act. Periods of exhausted soils and declining soil fertility are more characteristic of the Annecy catchment than the Erhai catchment. Fluctuations in crop yields probably occurred in the Erhai catchment as a result of periodic breakdowns in the maintenance of irrigation channels, as seen in the moribund and abandoned famous '18' streams irrigation system on the west bank of Erhai early in the 20th century, and due to drought. Cold weather, storm, and flood damage were more likely to cause direct damage to crops in the Annecy catchment as testified by the large number of compensation claims during the period 1730–1945 (Crook et al. 2002).

Traditional husbandry

What both sets of results from the sedimentary records do not reveal is that there was a striking difference in the different attitudes towards the mountain and the plain in both catchments. In the Annecy catchment communities were inextricably linked to the two through the use of summer pastures in a long tradition of transhumance, but in the Erhai catchment the dominant group in the catchment,[9] the Bai nation, largely felt it beneath them to indulge in work on the mountain and whilst individuals most probably at least from other minorities like the Loulou exploited some upland pastures in a piecemeal fashion there is no clear evidence for a more organised partial exodus of agro-pastoral communities based on professional transhumant roles as seen in the European Alps. At the turn of the

[8] Whilst basically true, Chinese farming was a multi-cropping system. For a typical South China farming calendar, see Fig. 3 on p. 146 of Elvin (2009).

[9] NB: As far as we know Bai in other parts of China have not employed such a rice standard.

20th century cultural distinctions existed between livelihood strategies in the Annecy and Erhai catchments. The Bai in the Erhai catchment were totally dependent on agriculture and specifically rice production that became known as the rice standard (Fitzgerald 1941). Han Chinese were almost solely limited to work locked up as commercial retailers and did not practice agriculture. Agro-pastoralism supported livelihoods in the Annecy catchment, with livestock rearing forming a much more important element of family and household livelihood strategies. Into the 20th century the landscape of the lower Miju flood plain has been altered dramatically by continued drainage and reservoir building aimed at intensification, whilst the Annecy catchment like other European alpine agro-pastoral areas (Girel et al. 2010) has retracted to a point where only tourism offers a sustainable livelihood, conditions that may ironically have introduced greater stability to this landscape.

Conclusion

In response to the questions set out at the end of the methodology section there was mostly a gradual and consistent, but at certain times seemingly non-linear and sudden, pattern of aggregation of environmental problems at Erhai. The emergence of environmental problems in the Petit lac d'Annecy catchment is perhaps more complex, providing signs of a more fragmentary pattern of periodic and cyclic crisis at Annecy characterised by an array of both linear and non-linear events. Both catchments have experienced similar types of environmental crisis, most notably flooding and erosion, in the relatively recent historic past with communities adopting parallel sectoral hydraulic engineering solutions albeit on different scales to these environmental problems that have taken similarly drawn-out times to rectify. Thus, an environmental threshold was clearly crossed in both main sub-catchments at roughly the same time. It is clear in both instances that decadal–centennial changes in land use, rather than higher frequency changes in precipitation, have exerted stronger controls on flooding and erosion in both catchments. It is now clear that the antecedents for these changes, whilst sharing some similarities, also differed in some key respects but with similar implications for catchment resilience.

In both locations, the high levels of landscape stability seen at the present time are in contrast to the environmental crises experienced in the past. But stability should not be simply viewed as a good measure of resilience (Gunderson and Holling 2001). At Erhai, history suggests that the impact of extreme monsoonal events has been suppressed by paddy farming and terracing. Landscape resilience to climate events therefore depends upon maintaining the intricate network of irrigation and drainages networks. Continued stability of the Erhai landscape at the same time as the trend towards agricultural intensification will rely heavily on agricultural and hydraulic investment to maintain paddy fields, terraces and river dykes, At Annecy, the modern land use trend is opposite, towards being more extensive, with forest replacing grazing in the upland pastures. There, the projected decline in snow cover may make winter and spring storms more direct and destructive. Higher forest cover will act to mitigate this impact in the winter months but in summer months may actually lead to lower river and groundwater levels, potentially exacerbating the problems of water availability, drought and fire. Both mountainous regions show the legacies of past human-environment interactions in the way they function today. Both offer lessons from the past about how they might function in the future.

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