Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion

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Abstract

Environmental history is a multidisciplinary enterprise united by shared interests in ecological change and the complex interactions between people and the environment. Its practitioners include expertise in the natural sciences, in history or archaeology, or in political ecology and related social sciences; but there is no agreement on a common agenda and limited success in bridging methodological and epistemological divisions that impede integrative and interdisciplinary research. World-systems history and environmental history also have overlapping interests in long-term change and matters of sustainability. The Mediterranean world sustained agricultural lifeways across some 8000 years, yet its environment has repeatedly been described as degraded, suggesting conceptual confusion between transformation and destruction. This paper is didactic in purpose and uses landscape histories for the Peloponnese and eastern Spain to show that the impact of recurrent, excessive precipitation events and of reduced quality of land cover are difficult to unravel, because they commonly appear to work in tandem. As a result (a) environmental change cannot be assumed or "predicted", but must be studied inductively by experts with science skills, and (b) cause-and-effect relationships demand an understanding of ecological behavior, for which humanistic insights are indispensable. Social science models highlight systemic relationships from socioeconomic and structural perspectives, but are less suited to deal with the complexity of environmental change or the contingencies exemplified by human resilience. Near Eastern, Greek and Roman agronomic writings offer elite "voices" that speak to cumulative technological change, scientific understanding, and the context of intensification. Rural voices can be heard through ethnography, and in eastern Spain are extended into the past by archaeology and archival research. In the absence of structural constraints, they reveal collective decision-making with respect to a shifting repertoire of agricultural strategies that take into account market opportunities, demographic growth, finite resources and environmental problems. Such adaptability spells resilience, and "good farming" is culturally embedded as a civic responsibility, both in the ethnographic present and in the older, elite agronomic writings. But if the "moral economy" erodes in the wake of food stress, tax extortion, instability, insecurity, or ideological oppression, there is little incentive to pursue long-term strategies, so that behavior focuses on short-term survival. The context for this dialectic of poor versus good ecological management may be structural, but cause-and-effect in the traditional Mediterranean world ultimately depended on ecological and human resilience. Long-term sustainability is similarly non-predictive. It depends on people, rather than social theory.
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1. Questions and framework

1.1. Introduction

Environmental history can be viewed as an over-arching frame within which several clusters of researchers

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(re)examine diverse but fundamental issues, ranging from climatic and environmental change to development, famine, and global inequities. That thematic diversity extends into the epistemological and methodological realm, with some groups favoring empirically grounded investigation and others a deductive, theory-driven approach. Some have experience in the environmental sciences, others do not, and the term scientism occasionally appears. But as is typical of new pluri-disciplinary arenas, participating members of the several subfields within the social and natural sciences talk mainly among themselves. What cross-disciplinary discourse there is, tends still to be inchoate rather than conflictive.

Examining the components of the new environmental history, there is a plethora of fresh ideas and a reassessment of old assumptions, with the emergence of new focal points. Confronted with historical interpretation and the complexities of nature and human behavior, we are all still grappling with high levels of contingency in such work. That would seem to call for much more communication and a creative, cross-disciplinary dialectic.

Seldom confronted are the inherent tensions between empirical evidence and social theory, or those between positivistic and non-positivist positions. Such polarizing dichotomies are simplistic, but can also be productive by drawing attention to important complementarities. Environmental history must be grounded in sound empirical data, acquired by theoretically informed research, and tempered by repeated reflection on the validity of assumptions. Yet our reading of landscapes and environments is mediated through culture, and environmental histories are about more than empirical data, because perceptions and ideologies shape human actions.

The environmental sciences can contribute substantially to an recognition of "what" happened in terms of change, but they are only one component of understanding "why" something changed. Causation in environmental history is more than just a complex "systemic" issue, because it involves intrinsically different variables that range from empirical to existential. A "scientific" metanarrative is insufficient here, because it does not privilege these other voices. But the conundrum of integrating such multidisciplinary components into a satisfactory overall methodology remains formidable.

By "integration" and "multidisciplinary" I am not necessarily referring to million-dollar projects by large teams of specialists. Such projects are important in their own right, but in their search for "big" conclusions to impress financial sponsors, contingencies may be played down in favor of seamless syntheses. Further, in view of the costs, big-team research more often than not is directed to rapid field studies, with middle-echelon specialists arriving or departing on complex schedules, and any interaction with local residents typically limited to "social science" interviews – that are a poor substitute for informal, personal relations and repeated conversations spread across three, four or even five seasons.

Better, in my experience, is a small-scale but intensive collaboration among researchers each of whom master several sets of skills, and who discuss issues on an almost daily basis for weeks at a time. In this way individuals broaden their perspectives, allowing for cross-disciplinary appreciation as well as integration of information and ideas. The goal should be a "deep" understanding, leavened by humanistic insights, and fully cognizant of the multiple contingencies that bedevil most efforts to determine cause-and-effect relationships.

This essay draws upon long-term personal participation in many small and large scale, archaeological collaborations, in order to open what I see as a discourse of negotiation. It is explicitly heuristic and experimental, in that it explores unconventional avenues to understanding, based in part on unlike methodologies that either qualify or sharpen issues of interpretation. It is contextualized by focusing on environmental history in the Mediterranean Basin; the selection of materials is based on cumulative personal experience; and the thrust reflects my deepening concern that true understanding is elusive.

1.2. The Mediterranean "problem"

The Mediterranean world represents an environment that has supported an agricultural way of life for more than eight millennia. One might intuitively interpret that as a measure of some sort of sustainability. But instead, the literature is replete with competing paradigms of *environmental devastation*. For Marsh [53] the problem was mismanagement. The destruction of primeval forests had contributed to violent floods, malaria, and a drier climate. He attributed the perceived sterility and "decrepitude" of Mediterranean landscapes to tyranny, ecclesiastical misrule, and slovenly land use by papists. Viewpoints such as this soon gave new Colonial authorities the power to categorize indigenous behaviors and attempt to impose controls on an ecologically destructive and ignorant native population [38], so in North Africa or Cyprus. Marsh's theme was reiterated by different Colonial administrations, but the villains were changed, now including destructive nomads, Turkish rule, and omnivorous goats.

A counterpoint was championed by Huntington [44,45], who attributed forest regression and abandonment of farmlands to a progressive decline of rainfall. This argument was later inverted, to claim that Mediterranean soils were destroyed by heavy rains related to climatic anomalies. These differing points of view, united only by their common belief in a ruined landscape, have continued to be debated ever since, in one guise or other.

Most recently, Grove and Rackham [37] have turned the question in a new direction, asking instead whether all that much has changed across the millennia. Although they overstate their case [17], they have opened a once inconclusive debate to critical scrutiny of assumptions grounded in misguided ecological evaluation, ethnocentric bias, Colonial policies, and imposed modernization or globalization. This is then an important and contemporary environmental issue, with implications for sustainability and much more.

This paper examines selected facets of the environmental history of the Mediterranean world, with its unusually good documentation, and from a variety of different positions. Initially an archaeological/historical overview is outlined to support a heuristic model of non-linear change, namely *a cyclic alternation of agricultural intensification and disintensification*. As illustrated by a complex case study of settlement and landscape history from Greece, long cycles of population growth were followed by decline, and serve to identify points of problematic interpretation. The Classical and Islamic agronomic literature provides direct voices to elucidate the evolution of understanding in regard to agricultural productivity, socioeconomic changes, and ideal ecological behavior. This generalizing framework is tested against another case study, from Spain, that uses ethnographic, archival, geoarchaeological and bioarchaeological observations to better appreciate alternative ecological points of view, as well as the role of cumulative experience and decision-making, under both ideal and less than ideal circumstances. It is suggested that such behavioral and humanistic components are critical to proper evaluation of the full range of interpretive problems.

The several, subdisciplinary genres of environmental history offer different criteria for "change", and may embed alternative views of causation, response and long-term implications. Recursive debate is called for, both to challenge assumptions and to discover inherent complementarities.

1.3. The ecology of prehistoric land use change

Agriculture in the Near East began over 10 millennia ago. Grains, some pulses, and the familiar Western herd animals appeared in the record at various times, but a standard repertoire of cultivation, herding, material inventories, and semi-sedentary living coalesced only gradually, during the sixth millennium BCE. Even so there were various permutations in early agricultural and pastoral production, in terms of the mobility of both livestock and cultivation, the dependency on herd animals for meat, milk products, or labor, and the interactions of early food producers with indigenous hunting, gathering, and fishing folk. One or other variant of this new economy dispersed rapidly across the Mediterranean, by leapfrogging from one coastal area to another.

Variants that were primarily pastoral developed quite early, but spatial parameters and seasonal patterns of mobility remain largely obscure. "Upland" pastoral economies, with supplementary cultivation, appear in Spain shortly after 6000 BCE. They had an inordinate impact on the vegetation [4], probably through the deliberate use of fire for clearing. It is useful to distinguish such *primarily pastoral groups* from more settled *agropastoral* ones, which presumably had different ecological priorities.

A significant advance came with acquisition of arboriculture, i.e., tree crops such as olive and grape, that in the Northern Mediterranean Basin are also associated with walnut and chestnut. Further fruit trees were gradually incorporated into this package, representing *Mediterranean polyculture*. As a three-pronged subsistence strategy (grains, herd animals and orchards), it reduced risk since each component was vulnerable to different hazards, and at different times of the year. The likelihood of all failing at once was small.

Mediterranean polyculture represents a long-term investment that assumes sedentary farming and some form of recognized property claims. With a highly complex annual schedule of activities, it requires a greater investment of labor, which is the basic meaning of *intensification*. It also is commonly associated with several other innovations, even though their timing is not always clear from the archaeological record:

(a) The animal-drawn plow, which allows cultivation of larger outfield areas than the hoe, an advantage with average or indifferent soils, particularly before an understanding of the link between organic fertilizers and productivity. The plow is a labor-intensive device, for both the draft animal and the plowman.
(b) Olives and grapes can be grown successfully on steep hillsides, permitting an expansion of agriculture to new ecological niches. Olive trees have open canopies and can also be grown in widely-spaced patterns amid wheat fields, without competing for space in the way that flax/linseed would. Orchard planting on hillsides stimulated efforts at artificial terracing in some areas, although that tradition is not convincingly linked with any one cultural heritage and was not universal on Mediterranean slopes even during the 19th century. Again the construction and maintenance of terraces is labor-intensive, and in reducing potential damage from soil erosion in the wake of de-vegetation, represents one of the earliest forms of effective conservation.
(c) The productivity of olives and grapes can readily exceed the consumption of an extended family, but

only after the technical mastery of oil-pressing and wine-making is acquired. Thus it becomes possible to produce a marketable surplus, rivaling that of grain, but more amenable to long-term storage and long-distance travel. "Commercial" success of olive oil and wine requires elite markets, and should therefore stimulate the growth of palace and proto-urban markets, while at the same time promoting intensification of the rural economy. With reduced subsistence risk and a commercial component, to facilitate inter-annual averaging of all production modes, rural populations should increase, as a condition for urban growth. Additional feedbacks might include the emergence of central-place hierarchies as well as intraregional and interregional economic integration. By potentially dampening the impact of local or regional harvest failures or longer term insufficiencies, and making possible centers of craft-specialization, it is probable that economic and demographic growth would be sustained.

1.4. Intensification/disintensification, world-system models, and environmental history

Intensification can be linked to systemic growth, a complex and interdigitated process much less susceptible to climatic anomalies than to warfare and the breakdown of economic integration. The central role of olive oil and wine in the development of complex societies in the Mediterranean probably helps explain their age-old symbolic or ritual significance. The earliest, incontrovertible evidence dates to about 3200 BCE, when wine and oil, witnessed by sealed and eventually inscribed jars, imported by the Egyptian court, infer commercial vineyards and olive groves in Early Bronze Palestine [16]. In addition to the technological testimony for such processing in Palestine, there also was an abrupt increase in the rank size and aggregate population of settlements (Early Bronze 1b) [36], reflecting economic growth. At latest by Mycenean times (Late Bronze, 14th century BCE), a similar system was in place in several parts of peninsular Greece.

Only loosely connected with intensification was another momentum to economic integration in the Mediterranean world, namely bronze metallurgy. Arsenical bronze that was mined in Almeria, Spain, was sometimes used in late Neolithic and Early Bronze Greece [63]. The impact of such early commercial links facilitated the emergence of a precocious complex society (Los Millares) around Almeria, where by 3000 BCE the charcoal of olive wood, wild or not, represented the most common genus preserved [61]. It would appear that selected areas of the Mediterranean periphery responded to novel ideologies by sociopolitical as well as ecological adjustments.

In the bigger picture, the production of surplus wheat, oil or wine, in combination with metallurgy, localized metals and alloys, and the timber required for faster ships, opened up the Mediterranean Sea for maritime commerce, that even extended to India and beyond. Mediterranean polyculture is more than an agronomic category, but an integral part of a network of long-distance commerce, representing energy and information exchanges, predicated on heterogeneous natural and human resources. First apparent during the Early Bronze Age, this early articulated system collapsed, not as a result of "abrupt climatic change", but in response to warfare, destruction and unrest during the late 3rd millennium [16]. It was revived in a more integrated form during the Late Bronze, and was again terminated for similar reasons after 1200 BCE. During the 8th and 7th centuries BCE it was resuscitated by "Archaic" Greek and Phoenician colonization or commercial hegemony, at which time olive and grape production established a firm foothold in the Western Mediterranean. Integration was reinforced after 200 BCE by increasingly direct Roman control.

These three surges of intensification, culminating about 3000 BCE, 1300 BCE, and again perhaps 100 CE, were followed by agricultural disintensification and politico-economic simplification, in effect, ruralization. Such quasi-cyclical structures find support in an increasing number of archaeologically-constructed, regional settlement histories, for example Etruria [57], the Greek isle of Keos [26], or the Argolid of the Peloponnese [48,65]. Periodically, such areas experienced an increase in settlement number and size over time, until there was retraction and local abandonment. As often as not, such settlement histories are cyclical, even if the cumulative trajectory across prehistoric and historical time is one of net growth [9]. Settlement histories are in turn linked to population growth and decline, related to so-called millennial long waves ([10, ch. 15], [1,50,72]). There is a *systemic interlinkage between ecology, intensification, demography and politico-economic integration at the regional level.*

There are obvious analogies between this premise and world-systems history, which in one form or other focuses on intersocietal networking to examine long-term change at an increasingly global scale [25,29]. Variables not only include integration/disintegration of economic networks but may also run the gamut from environmental deterioration to Malthusian overshoot or warfare and insecurity. But these are preeminently economic and structural models, with heuristic rather than explanatory value. At their best they draw attention to pathways that may link historical experience with contemporary problems such as population explosions, resource degradation, sustainability, 'failed states', or globalization. Such perspectives should be valuable for environmental histories, and indeed they are. Their current limitation is that the "environmental content" of world-systems models is abstract, and more predictive than empirical. There is still too much reliance on derivative or dubious syntheses of environmental history (for example, [27]), and more energy is expended on debating modes of accumulation than on acquiring skills in ecological understanding. "Degradation" and sustainability are about more complex issues than economic rationales.

This essay will examine the intricate nature of environmental impacts over the long term, to highlight the difficulties of cause-and-effect inference. I will argue that historical ecology is never self-evident, that causation is elusive, and that human perceptions and behavior are integral to an understanding of "change". Perhaps that will offer a bridge for a discourse with historians and world-systems theorists.

2. Cyclical change on the Greek Peloponnese: a didactic case study

An appropriate archaeological survey for a case study of intensification cycles is offered by the Southern Argolid, on the southeastern tip of the Peloponnese (Fig. 1). This is large area (350 km^2) that was systematically sampled and surveyed for artifactual and architectural remains, identified and discussed by archaeological period, and documented with a massive inventory of 328 sites [48, pp. 415–538]. Spanning the duration of the Holocene, sites were estimated as to size and density, to provide population estimates for each occupation phase. Unprecedented sites were also mapped with respect to changing soil resources and integrated into a model study of landscape change, as reflected in soil erosion, related slope deposits, and floodplain behavior. A major advantage is that landscape history can also be directly combined with that of the Argive Plain, located 30–40 km up the Gulf of Argos.

The Argive Plain has a detailed palynological study from a core in Lake Lerna [46,47], while soil and sediment history, including the Late Bronze urban center of Tiryns [49], are the subject of a monograph ([75], also [66,74,76]). Finally the data from the Argolid can be complemented by studies from Olympia and Messenia, in the Western and Southwestern Peloponnese, respectively. The broader area represents an obvious choice in that it combines a quasi-rural archaeological survey, an urban site, adjacent comparative investigations, and a constellation of top-echelon researchers, who worked here across many field seasons.

2.1. Settlement history and population of the Southern Argolid

We begin by sketching a familiar contextual scenario, but emphasizing ecological perspectives. Population estimates based on archaeological interpretation and ethnographic analysis potentially serve as heuristic models to highlight cyclical change. Fig. 2 plots the numbers given by Jameson et al. [48, Tables B.6–7 and text] as a curve against archaeological time, adopting a quasi-logarithmic scale (cube root) that identifies trends. As a caveat the dating framework prior to the 1st millennium BCE is based on relatively few and mainly older radiocarbon dates.

The Neolithic record is modest and incomplete except for one major cave site. The Middle Neolithic (perhaps c. 5700–5300 BCE) in the Argive Plain may be followed by a settlement hiatus, and the Argolid remained marginal to a substantial evolution of Neolithic agriculture in the basins of central Greece. Population increased with the Early Bronze, probably in response to intensification and trade in metals (and wheat?). There is no evidence for olive, but grapes were being grown [43,51], although settlement was limited to the areas of best soils, implying dry farming. At the end of Early Bronze II, sites were destroyed, suggesting sociopolitical unrest or migration c. 2600 BCE, that resulted in disintensification and population decline across as much as 600 years.

Although elsewhere in Greece olive cultivation and the plow appeared during the Early or Middle Bronze [40], the population of the Argolid only increased rapidly with the Late Bronze, especially the Mycenean era (c. 1400–1190 BCE). During the Early Bronze there had been a three-tiered hierarchy of settlements, based on town/village sizes and the quality of construction and trade pottery in larger houses. This incipient central-place hierarchy was reconstituted with the Mycenean – a complex society with conspicuous status differentiation that was centered around Mycenae and Tiryns. Commerce was revived, olive cultivation and vineyards were productive [51], and it is likely that hillside terracing had been introduced [35]. The use of upland caves further suggests pastoral activity. But the Mycenean palace-fortresses and the commercial network they represented [39] were destroyed c. 1190 BCE. The Late Bronze (Helladic) IIIC that followed is sparsely represented in the Southern Argolid, and it is tempting to associate this event with external forces.

However, Tiryns may have been destroyed by an earthquake, and it was rebuilt on an impressive scale to house a 25 ha settlement, that suggests a simplified social hierarchy [49]. The crop selection remains the same, but a reduction of weedy plants may indicate a less intensive form of agriculture [52]. A smaller concentration of domestic animal bone and a higher ratio of wild forms suggest a lower population and greater emphasis on hunting [29], perhaps no longer a prerogative of the elite. Thus IIIC Tiryns remained an important place, although socially transformed; only after a century or so did it decline to the point of abandonment [49]. The Late Bronze Age in the Argolid

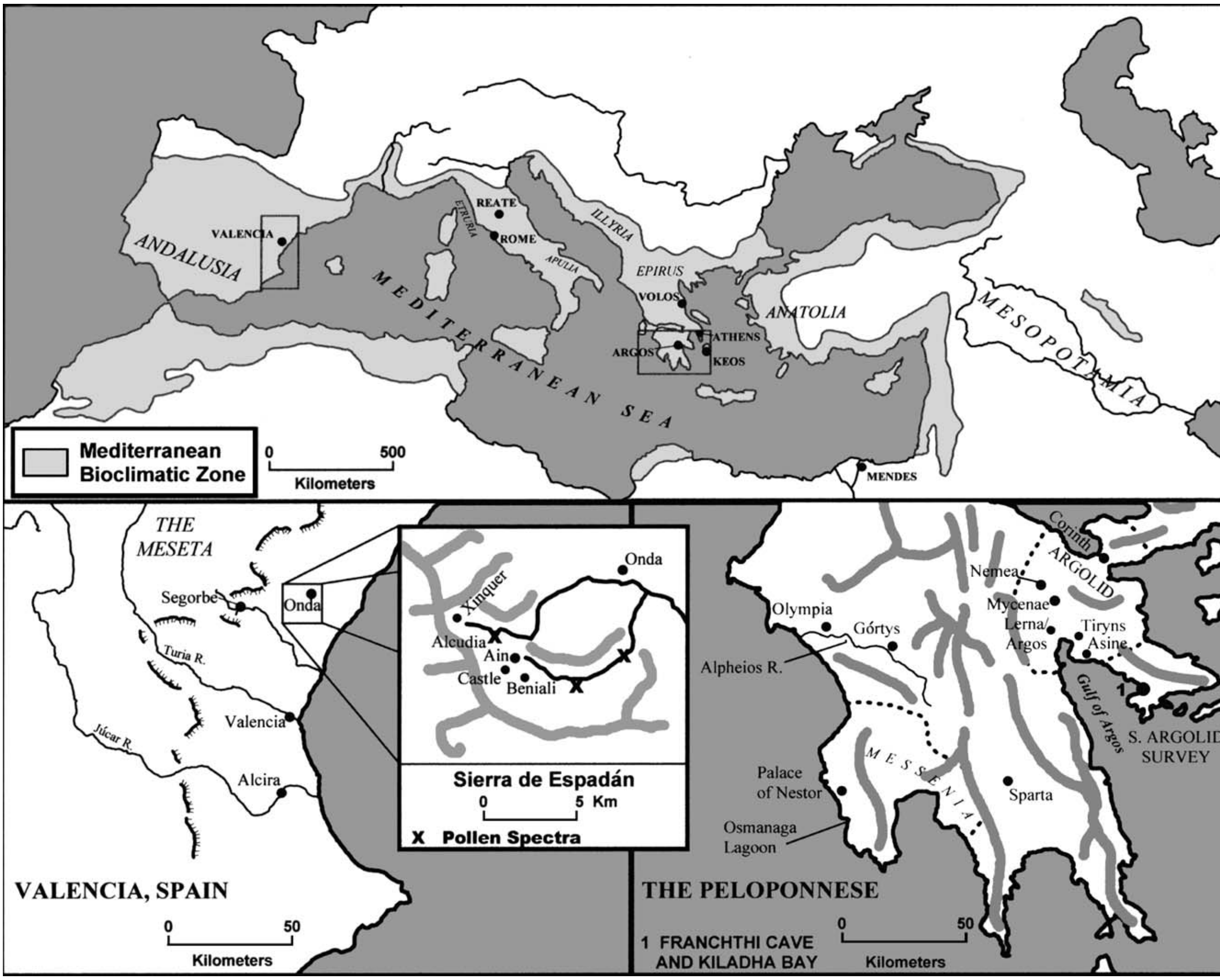

Fig. 1. The Mediterranean Basin, Peloponnese, and eastern Spain, showing locations discussed.

did not come to an abrupt end, and potentially commercial crops continued to be cultivated.

The ensuing "dark age" with its settlement reconfiguration is poorly understood, but coincided with Iron Age migrations, presumed to be transhumant pastoralists, across parts of the Peloponnese. In any event, pottery styles changed. During the 8th century BCE strong economic and population growth are once again apparent in Archaic Greece. City-states emerged and overseas expansion began, perhaps more as a strategy of commercial hegemony than as a stereotypic outlet for excess population. Demographic growth slowed during the Classical period (c. 480–350 BCE), declining after 300 BCE in response to repeated bouts of war and the marginalization of Greece within a larger and more complex commercial network. Decline was halted with establishment of the *pax romana* under Augustus, with renewed growth predicated on a new pattern of settlement, when Greece became part of the core of the Eastern Roman empire. Prosperity probably peaked early in the reign of Justinian (527–565 CE), before a recessionary spiral fueled by plague, warfare with Persia, the Arab conquests, immigration of Slavic pastoralists, and breakdown of the monetary economy. There appears to be no visible archaeology for this second "dark age" c. 650–1000 CE, and most place names of settlements were lost. The remaining inhabitants presumably turned to pastoral pursuits.

Repopulation by Anatolian (?) farmers apparently followed, and the later invitation of Albanian pastoralists implies massive population during the Black Death of 1348. Under the Venetians and Turks (1394–1829), land use patterns appear to have been stable and conservative [65]. Following Greek Independence (1831) the population and olive cultivation exploded, until agriculture became increasingly obsolete during the mid-1900s.

The cyclical trace of population growth and decline shown in Fig. 2 is representative of processes not unique to the Peloponnese, even as historical details differ from region to region. The responsible factors and social problems are difficult to evaluate. But integration of economic networks by Late Bronze times was clearly important in stimulating both growth and demand, or the production of agricultural surpluses through intensification. Destructive warfare, economic disintegration, or natural disasters such as earthquakes were probably important in decline and disintensification, through feedbacks that would have undermined political authority and security, to favor rural flight into the pastoral sphere or to open the gates to pastoral immigration.

This representative metanarrative offers a socioeconomic context that invites questions about the significance of such cyclical changes for land use, vegetation cover, and soil stability.

2.2. Interpreting vegetation and land use change

Land use history in the Argolid is to some degree recorded by a detailed pollen profile from Lake Lerna in the centrally located Argive Plain due to Jahns [46,47]. Seven, fairly consistent radiocarbon dates provide a uniform sedimentation curve when calibrated, so that ages of the pollen zones can be approximated from the pollen core. Based in part on Suzanne Jahns, the following critical and interpretive review summarizes key numerical data, identifies the ecology or agricultural significance of particular genera, and attempts to characterize the mosaic of habitats and land use on the slopes or uplands and lowlands. Ideally, resolution would have been finer-grained if the sedimentation rate had been faster than 1 cm/15.5 years, but one spectrum (at 5 cm intervals) per 77 years is actually slightly better than average for long cores. On-site archaeobotanical materials (seeds, charcoals) and animal bone have been studied [30,51,52], but suitable sites do not appear to exist for the last 2500 years, when macrobotanical remains would have been particularly helpful. Even so, the Lake Lerna pollen record, rarely cited in the

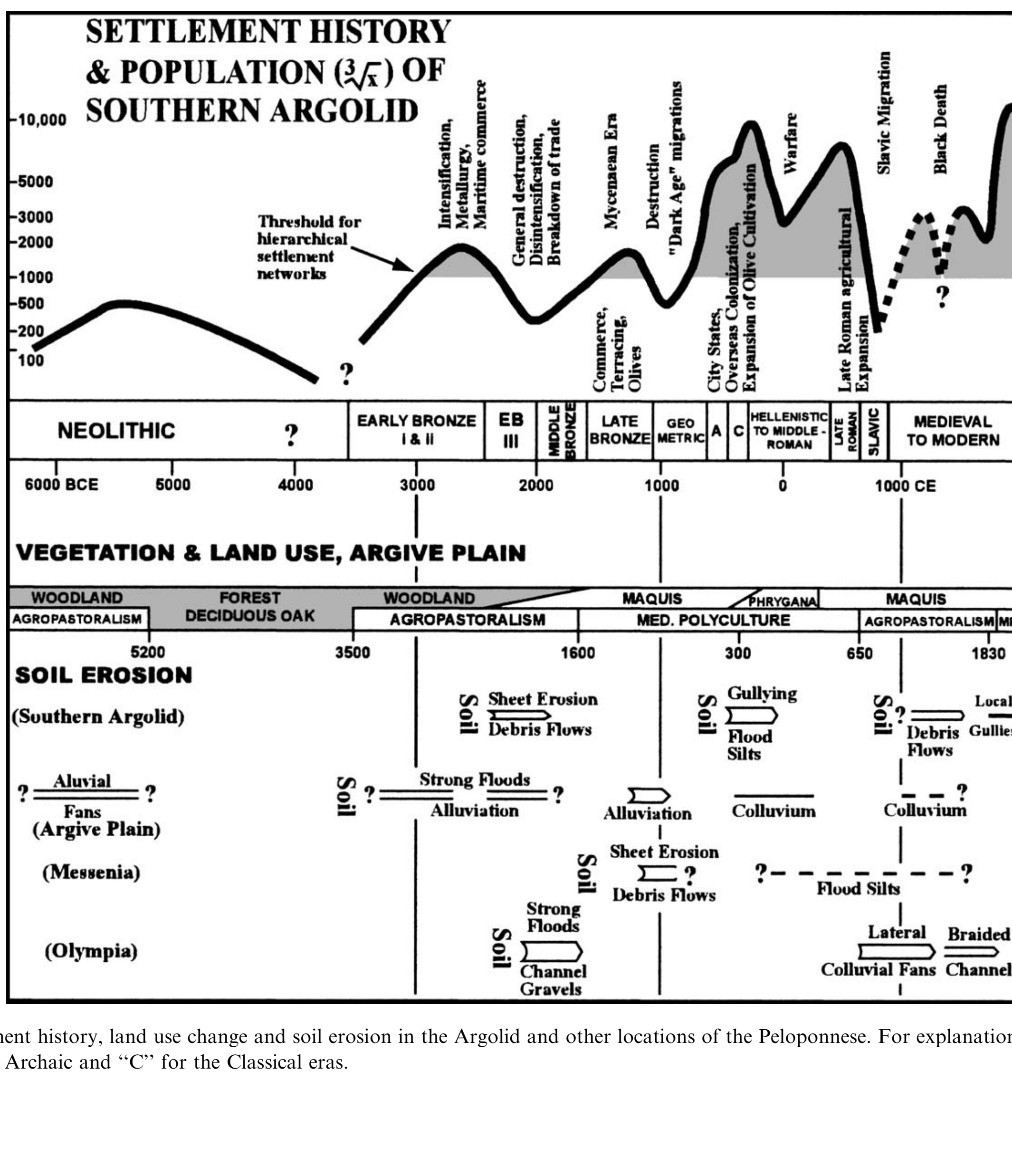

Fig. 2. Settlement history, land use change and soil erosion in the Argolid and other locations of the Peloponnese. For explanations, see text. "A" stands for the Archaic and "C" for the Classical eras.

anglophone literature, is better than any linked to a comprehensive archaeological project in Greece.

At the base of the core (c. 6200–5200 BCE), deciduous oak pollen runs 40–50%, together with ancillary hazel, manna ash (*Fraxinus ornus*) and eastern hornbeam (*Carpinus orientalis/Ostrya*), trees that are favored by human activity. The Mediterranean component is represented by evergreen oak pollen (8–15%), mainly Kermes oak (*Quercus coccifera*), together with characteristic woody shrubs (pistachio and *Phillyrea*) and juniper. The herbaceous ground cover is dominated by the large family of the Asteraceae, and specifically its often "weedy" subfamily, the Liguliflorae (with latex), including or together with taxa such as *Polygonum*, *Sarcopoterium*, *Mercurialis*, *Rumex*, *Artemisia* and *Centaurea*, mainly weedy in this context. Large grass pollen traditionally identified as Cerealia are more problematical in the Mediterranean, with its wild counterparts, but since their co-variation with other Poaceae is not particularly close, a qualified attribution of this category to such grains is reasonable.

The first pollen horizon, as an assemblage, suggests an open, deciduous oak woodland, interspersed with tracts of maquis and "weedy" fields. Compared with the subsequent horizon (5200–3600 BCE), which has 60–80% deciduous oak pollen, little evergreen oak (5–8%), and a minimum of weedy plants, this first horizon suggests a moderately disturbed environment, impacted by pastoralism and farming, even though the numbers of early and middle Neolithic occupants before 5200 BCE was small. By contrast, the horizon after 5200 BCE argues for a dense, deciduous oak forest, providing a model for minimally disturbed land cover, and implying no more than an incidental Late Neolithic presence.

About 3500 BCE, with advent of the Early Bronze, deciduous oak declined abruptly to values around 40%, while evergreen oak increased to 10–20%. Hornbeam, which is promoted by coppicing, rose to over 10%, and pine may have spread on cleared ground. Olive, probably wild, is recorded consistently but in low counts, and in conjunction with increasing evergreen oak, heather, *Phillyrea* and Cistaceae would identify the presence of maquis. The Cerealia tally 2–3%, only half that of the mid-Neolithic horizon, and "weeds" are poorly represented. There was partial clearance, and upland grazing must have favored the expansion of Mediterranean scrub and shrubland (maquis), but overall the assemblage suggests fairly modest land use intensity. This contradicts the conclusion of Whitelaw [71, p. 152] that "Early Bronze Age populations…were literally eating their way through the landscape, denuding slopes as catastrophic soil erosion eventually followed".

During the Early Bronze III and Middle Bronze (c. 2600–1600 BCE) there was no forest regeneration, but hornbeam, hazel, ash and the Cerealia declined abruptly, the latter to 1–2%. Pine and olive increased but fluctuated strongly. Heather, pistachio and *Phillyrea*, as well as the classic "disturbance" group of the Chenopodiaceae and Amaranthaceae increased. This argues for an expansion of maquis at the expense of once-cultivated land, and hints at introduction of cultivated olives. An expanded pastoralism is implied but does not seem to have been particularly destructive of the original biota.

A steady decline of deciduous oak pollen to 25% marks the Late Bronze (c. 1600–1050 BCE), with an increase in hornbeam and ash, and the first appearance of walnut. From the Mediterranean shrubland there are notable increases of olive, *Phillyrea*, heather and pistachio. There is a spectacular jump of the Liguliflorae and Caryophyllaceae, with expanding *Artemisia*, Chenopodiaceae, *Sarcopoterium* (a pasture weed), *Polygonum* and *Plantago lanceolata* (a field or pasture weed), among the disturbance plants. But the Cerealia group rose to 5%. The assemblage shift implicates a partial replacement of woodland by maquis, with pastoralism moving to the uplands, as olive cultivation began to expand and agriculture took over the lowlands. In fact, this is the first pollen zone that suggests intensified agricultural land use. Shipbuilding would have required cutting of timber, but ships and fleets were still small, so that tree harvesting could have been balanced by regrowth.

The macrobotanical and faunal materials from Tiryns provide a more three-dimensional picture of Late Bronze Tiryns. Olive constitutes the most common wood and the abundance of olive pits supports the inference of olive groves; the prominence of olive, grape and fig suggests polycropping of fields, otherwise devoted mainly to cultivation of a variety of emmer wheat and barley, with commensal weeds [51,52]. Oak charcoal (a half deciduous) and pine are common enough to suggest patches of woodland, while elm or *Celtis* would imply at least some deciduous, riparian zones, although the presence of tamarisk points to occasional sandy or gravelly channel stretches [51]. Cattle and sheep were the most important livestock, with sheep increasing in size through selective breeding, but cattle and other stock were smaller than in Early Bronze times [30]. Wild animals constitute only 5% of the animal bone, but the list includes three genera of deer, as well as boar, bear, lion and lynx, supporting the inference of residual woodlands [30]. In other words the on-site biotic evidence is compatible with the palynological interpretation suggested here.

Comparison of the charcoal evidence of Late Bronze Tiryns with that of Early Bronze II levels at the occupation site of Lerna is informative. Although the sample is small (63 identified pieces), the dominant forms in order of importance are pine, olive wood, oak, and fir (*Abies*) [43]. Pine and fir may well have been found on nearby, lower mountain slopes, so that their presence in the pollen profile was not primarily a matter of long-distance transport. Fir charcoals are absent in Late Bronze Tiryns, suggestive of reduced woodland diversity, perhaps affected by selective cutting.

Resolution and dating of the pollen curve are not quite adequate to pick up the detail of the post-Bronze ''dark age'' and subsequent recovery. There is a single spectrum with a short spike of deciduous oak and reduced olive and weedy plants, followed almost immediately by a strong peak of olive and weedy plants. This would suggest only a brief quasi-abandonment, followed by a rapid switch to large-scale olive cultivation, even during the early Iron Age.

From c. 800–300 BCE, deciduous oak continued to decline, until early Hellenistic times. *Phillyrea* and heather expanded, and other, open-country forms such as the Cistaceae, Amenome and Ranunculaceae became important. Olive pollen fluctuated around 15% and the Cerealia remained strong, with hornbeam and ash present. The Liguliflorae reached new peaks, while *Polygonum*, *Sarcopoterium*, and *Plantago* continue, but *Artemisia* and the Chenopodioceae decline. This now suggests a classic landscape of Mediterranean polyculture, with olive groves and vineyards, and most of the uplands reduced to increasingly open maquis shrub rather than scrub.

Towards 300 BCE, this cultural landscape was in decline. First evergreen oak decreased sharply, then the Mediterranean indicators and the Liguliflorae. Next pine pollen doubled while olive dropped by half, with a temporary re-expansion of deciduous oak. Eventually evergreen oak resurged, the Mediterranean indicators recovered, and Chenopodiaceae began to explode. Olive collapsed stepwise by 700 CE. What does this complex pattern of differential change mean? In the uplands, maquis was almost eliminated for centuries, without an apparent eruption of weedy plants, but an expansion of pine, perhaps eventually replaced by deciduous oak. If that is correct, pastoral pressures were reduced for some time, perhaps after a greater incidence of uncontrolled fires, that converted the maquis into dwarf shrubland (*phrygana*). About 200 CE maquis began to re-establish itself, but the phenomenal expansion of Chenopodiaceae suggests extensive tracts of desolate farmland in the low country. A Late Roman revival of agriculture is not obvious from the pollen record.

During the 10th century, pine once more invaded the uplands at the expense of evergreen oak, but heather and pistachio were well developed, and *Sarcopoterium* peaked, together with the Cerealia. This also was the landscape of Venetian and Turkish times, with subsistence grain-farming in the lowlands, and a *phrygana* with dwarf juniper on the uplands. Olive cultivation only resumed after Independence.

2.3. Interim palynological inferences

(a) The pollen core of Jahns [46,47] from Lake Lerna opens a lucid, if qualified, land use history for the Argolid. It must be understood as ''qualified'' since, like the archaeological settlement history, interpretation involves assumptions and uncertainties. But the information is an order-of-magnitude improvement on conjecture and, in conjunction with the archaeological/historical inferences and the physical landscape history (see below), provides a strong analytical tool.

(b) The Jahns core is almost ideal in terms of pollen productivity and hence pollen counts. By comparison two shorter cores from the Southern Argolid [70] produced only small or unacceptable counts per spectrum; in combination with unproductive samples, their data are too widely spaced and fail to pick up the fine texture of the Lake Lerna profile. Another local profile, from a submerged core in Kiladha Bay [7] is undated and poses insuperable problems of interpretation. A relatively detailed pollen profile is available from Osmanaga lagoon (Messenia, Southwestern Peloponnese), backed up by a systematic study of modern vegetation communities and their pollen rain [77]. Such data would allow principal components analysis of the fossil assemblages. But in this case there are serious dating problems that are not satisfactorily resolved. Finally, a core in the Nemea Valley [3] has only a few data points, being mainly unproductive. Not all palynological studies of deep cores are suitable to interpretive analysis of land use change over time.

(c) The only pollen core of comparative value is that of Halos in Thessaly, extracted in the bay near Volos [6,7]. Three of the four dates fall on a linear curve and suggest some confidence in the chronology. The Halos profile suggests an open deciduous woodland with large patches of maquis or phrygana and weedy fields after 3800 BCE or so, with olives and grapes prominent during the Early Bronze I and again during the Middle Bronze Age. Mediterranean polyculture was firmly established during the Late Bronze. But after about 1000 BCE the woodlands were in strong decline and polyculture essentially disappeared, with only a weak resurgence of olive c. 400 BCE. The absence of evidence for Classical intensification may have been a consequence of marine transgression, but that is not a convincing explanation. The importance of the profile lies in identifying olive cultivation here during part of the Early Bronze Age.

(d) Points of apparent contradiction between the settlement and land use histories for the Argolid draw attention to underlying assumptions that may or may not be warranted. So, the comparative biotic impact of Neolithic land use appears excessive for several hundred inhabitants while that of the Early Bronze I/II seems inconsonant with a population of perhaps 2000. This incongruence is not unique to the Peloponnese, and may well reflect different technologies, with Bronze Age land use being less destructive, as a consequence of cumulative experience with conservationist strategies developed by trial and error [15]. Then again, the Early Bronze and Late Bronze population levels were similar, but the biotic impact of the latter was not only more complex but also destructive.

The issue here may be a different political economy, that placed greater demands on farmers and gave them less autonomy in decision-making.

If the dating is correct, the explosion of olive cultivation at the beginning of the Iron Age suggests that assumptions about total population for the Peloponnese may be wrong; it also fails to explain why olive production should expand at a time when there were only insignificant urban or overseas markets. The sorry state of conservationist practice during Hellenistic and Roman times does not necessarily contradict impressions projected by a careful reading of the historical sources, but nonetheless casts a novel perspective on early agricultural decline and perhaps uncontrolled pastoralism. For both this era and the Middle Ages it becomes apparent that political economy and land tenure issues deserve much greater attention (compare [26], for the island of Keos) with respect to ecological behavior.

(e) There is a significant gap between sketching out biotic and land use change, on the one hand, and offering an evaluation of landscape disturbance, damage or degradation on the other. Change *is* no less than "disturbance", and stop-and-go "change" was continued on a moderate to intensive scale ever since about 3500 BCE. But when does it become "damage" or "degradation", and by what criteria? The only sound case for "reversibility" was during Late Neolithic times. We must therefore invoke a new criterion, the disequilibrium of soil cover and stream behavior, as explicated below.

2.4. Soils, streams and landscape disequilibrium

It will now be argued that the ecological significance of cumulative biotic impact and land use change is tellingly reflected in the landscape destabilization recorded by accelerated soil erosion and stream alluviation. To do so, we first review the basic evidence for such phenomena in the Southern Argolid and Argive Plain, before selecting the "geo-archive" of Olympia, in the Western Peloponnese, as a heuristic example of how thresholds of disequilibrium are crossed, and how a soil/hydrological system "crashes".

2.4.1. Repeated destabilization in the Southern Argolid

There are four bodies of sediment in the Southern Argolid that record landscape response to biotic and land use change of an order of magnitude sufficient to induce destabilization. This evidence has been marshalled by [56,48].

The youngest of these represents recent or ongoing gullying, reflecting agricultural devolution and terrace neglect during the 20th century. The next to last phase resulted in stripping of slope soils by accelerated sheet erosion, with rapid debris or mud flows that entrained a mix of soil and rock rubble, particularly in the mid-sectors of the valleys; these are covered by stream flood deposits, that continue into the lower valleys. Such features are localized and are 40 cm to 2.5 m thick. The youngest sherds within these sediments are Late Roman (i.e., 400–600 CE), and a Venetian farm is shown atop one such exposure on a representation of 1705. Found downstream of areas resettled in Medieval times (c. 1000–1200 CE), they are attributed to "rapid and careless clearance" by Anatolian colonists [48, pp. 408–409]. Within the frame of 400 and 1700 CE, an approximate age of 1000–1500 CE seems plausible. Subsequent soil development was minimal.

An earlier episode of erosion was more destructive. Thick flood deposits accumulated on the valley floors, probably in response to gully erosion on the slopes. These flood loams also are thickest in the middle valleys (1.5–8.0 m). The youngest sherds within such sediments are late Classical to early Hellenistic (c. 400–250 BCE), with Hellenistic to Early Roman archaeology found on top. They are attributed to "abandonment of agricultural lands" coincident with "a changed settlement pattern and late Hellenistic economic decline" [48, p. 398]. A date of 300–0 BCE can be suggested, and a distinct soil formed on such beds, indicating protracted slope stabilization.

The earliest Holocene sediment bodies in the Southern Argolid again consist of debris flows, suggesting episodes of sometimes catastrophic slope failure in areas of Early Bronze land use. The youngest sherds within these deposits are Early Bronze II, and a Late Bronze site is located on their surface, which is weathered by a reddish, clayey soil. The authors suggest three possible explanations: (1) erosion in the wake of Early Bronze land clearance; (2) erosion following abandonment, or (3) a period of exceptionally heavy rainfall [48, p. 355]. Discussion is best deferred until after review of soil erosion on the Argive Plain.

2.4.2. Parallels and differences in the Argive Plain

In the Argive Plain, the oldest Holocene sediments were deposited by steep streams emerging from the mountains, in the form of alluvial fans along the margins of the plain. They rest on strongly weathered Pleistocene beds or overlap younger lake beds, and may be 3 or 4 m thick; consisting of clayey sands and sandy gravels, they are interbedded with channel beds. This early unit contains reworked Neolithic sherds and the strong, terminal soil embeds Early Bronze sherds ([75, pp. 27–29, 35–43, 50–52, cross-section 2, profiles SP-05/6/7]). Prior to 3500 BCE, the Lake Lerna core has two sections of sandy silt, the ages of which can be interpolated as prior to 5300 BCE and c. 4550–4150 BCE. Alluvia of this age have not been reported from elsewhere on the Peloponnese, with possible exception of the Nemea Valley (A. Demitrack in Ref. [73]), which seems to preclude a climatic anomaly. But the Neolithic vegetation was notably disturbed, and the localization and development of sediments are compatible with soil erosion in upper catchments as a consequence of hillside pastoralism. An age prior to 5300 BCE is preferred.

The second episode of soil instability in the Argive Plain was a major one [75, 23ff., pp. 52–54, cross-sections 1–5], with thick stream gravels south of Tiryns deposited as an alluvial fan that prograded well into the shallow Gulf of Lerna. Cobble gravels at the base, followed by interbedded gravels and loams, indicate unusually high energy. Near Argos this alluvium, with reworked Early Bronze sherds, rests on lake beds with peat horizons dated c. 6330 and c. 3800 BCE, and at Dalamanara underlies lake beds with a date of c. 2560 BCE. There appear to be two such alluvia, separated by brackish-water beds near Tiryns, the younger perhaps recorded by the sandy silt in the Lake Lerna core from c. 2450–1800 BCE. The alluvial fan of the Inakhos River advanced well beyond the limit of the Neolithic counterparts, suggesting abundant and sustained peak discharges. Given that Early Bronze occupance was "light" in the palynological record, despite dense Early Bronze II settlement on the Argive Plain, high-energy deposition would be best explained by recurrent, exceptionally heavy rains during the period c. 3500–1800 BCE. This is compatible with the old debris flows in the Southern Argolid, which are of comparable age. Early to Middle Bronze alluviation in the Argive Plain and corresponding shoreline progradation were a result of climatic anomalies and should not be confused with more modest alluvial fills of the Late Bronze.

Midway through the Late Bronze (Late Helladic III B 1/2, c. 1250 BCE) the river upslope of Tiryns shifted its course, depositing a c. 2–5 m mass of crossbedded sand and gravel on the north and eastern sides of the site in a single flash flood [75, figs. 41–42]. This is not the only sediment body loaded with Late Bronze sherds [75, cross-sections 2–5; 76], and the profiles at Tiryns fix the initiation of accelerated alluviation midway during the Mycenean era, with its probably intense impact on land cover. Nothing comparable is evident in the Southern Argolid, supporting a land use interpretation. But this flood did not lead to the demise of Tiryns (as per Ref. [67, Table 6.1].

Post-Bronze Age soil erosion left little of a conspicuous record on the Argive Plain, perhaps because vulnerable slope soils had already been largely destroyed. Most widespread are incremental colluvial deposits of up to 2 m thickness, along the footslopes. A late Classical or Hellenistic house was occupied midway during such accumulation ([75, pp. 56–59, cross-section 2, SP-11]), suggesting pastoral disturbance in the hills during the post-Alexandrine agricultural decline. There also are some sandy colluvia with basal, Medieval sherds and terminal gravels ([75], SP-03), which would be a millennium younger. The presence of some pebbles in sandy sediment of the Lake Lerna core suggests an episodic influx of stream alluvium during the time span c. 200 BCE–1200 CE.

2.4.3. Complex disequilibrium at Olympia

Complementary observations from other parts of the Peloponnese shed further light on episodes of landscape destabilization. To the west, in the Messenia district, soil erosion was fairly rapid as a result of weak, erodible bedrock (marls). Late Bronze architectural remains have been badly impacted, and debris flow and slump deposits rest on the already destroyed palace of "Nestor"; the deposits include abundant Late Bronze (Late Helladic IIIA and IIIB pottery, the latter sometimes showing signs of burning) [77, pp. 564–566]. A post-1190 BCE date is therefore clear, as is the case for anthropogenic erosion.

Important details can be identified at the site of ancient Olympia, in the Western Peloponnese [8, pp. 338–346; 31; 37, pp. 291–296]. The axial river, the Alpheios, aggraded coarse gravel, that rests on tree roots dated to c. 2000 BCE, indicating a post-Early Bronze age, while Late Bronze structures on its surface suggests a Middle Bronze age for the gravels. Their lithology includes both local and distant watershed components. It is possible that destructive land use contributed to its accumulation, but it would not have been possible without a high recurrence of excessive high peak discharge events, which overwhelmingly came down the Alpheios, rather than its tributaries. That argues for a climatic anomaly.

The site of Olympia was occupied since perhaps 1000 BCE (the Olympic Games being formalized in 766), with construction continuing atop the gravel terrace until Late Roman times. Soon thereafter the Kládheos tributary behind the site complex began to eject sediment that covered the fallen columns of the Temple of Zeus (destroyed by an earthquake in 522 or 557 CE), burying most of the sanctuaries with 3–8 m of calcareous silt. The youngest archaeological vestiges under this silt are coins of 567 and 575 CE, but there also are settlement remains, variously attributed to a Byzantine village or Slavic shepherds. This sediment is not from upstream via the axial river, but locally derived from the erodible marls of the steep slopes along the Kládheos, and linked to colluvial footslope deposits at the mouth of the small gorge, the waters diverging into a number of distributary channels that dip down towards the Alpheios River. This was a typical stream response to rapid soil erosion, with plugs of sediment forming silt fans that also project from the mouths of other key tributaries. Further upstream in the Alpheios drainage at Górtys, there are two generations of such post-Roman silts, the younger embedding a Byzantine chapel. Preliminary observations of post-Classical/Byzantine alluvia in the Nemea Valley (A. Demitrack in Ref. [73]) suggest a similar pattern.

Slope erosion and tributary sedimentation at Olympia probably began within a century or so of 600 CE, and may have happened in several stages. At the time of the first visitor's plan (1811), the southeastern quadrant of the site (including the hippodrome and part of the stadium) had already been destroyed by stream downcutting, and lateral undermining of the early Medieval fan by the Alpheios River. When first surveyed in 1880 the Alpheios formed an 800 m-wide span of interweaving, braided channels, moving through sands and gravels. But by the 1960s, active floodplain width had been reduced by a third, with a meandering channel in between [8,31].

2.4.4. A non-equilibrium model for Olympia

The historical behavior of the Alpheios and its tributaries as critically reviewed above illustrates how streams react when ecological behavior damages the quality of land cover, with attenuated destabilization across one or more decades. But it is the recurrence of extreme precipitation events that triggers or accelerates disequilibrium, by actively eroding vulnerable slopes via sheetfloods or gullying. Soil and soft substrate materials are initially deposited in the form of poorly sorted colluvium on concave footslopes, the excess sediment carried into streams by heavy rain events. Coarser particles such as sand or gravel are laid down in the channel, while flood waters rapidly spread silt and clay across the floodplain. This can rework surface artifacts or bury archaeological sites. In response to the evident ecological damage, land use pressures may then have been relaxed, allowing some vegetation recovery and stabilization of the slopes (Table 1).

Unless these processes are repeated, this is where most current soil erosion histories stop. But the channel history of the Alpheios shows that conditions did not return to "normal" until the 20th century, because braided channels are atypical of the Mediterranean world. The early to mid-Medieval silt fans had once projected down to the channel, locally constricting it and creating irregular gradients. But channels deepen to accommodate high flood volumes; with very strong floods, a channel is entrenched in constricted segments, creating a stepped floor that erodes headward during subsequent peak discharges, sometimes so rapidly that bars of very coarse sediment build up downstream. The channel then undercuts its banks, to accommodate further extreme floods, since channel banks are easier to erode than a gravelly bed (Table 1). Eventually major rivers form broad, shifting channels with braided sweeps of sand and gravel.

If slope erosion in the tributary valleys is periodically renewed, sheets of sand and gravel eventually cover what is left of the valley floors. Only a significant stabilization of the tributary valleys, with a good ground cover, that can reduce the rate and amount of discharge after heavy rains, will allow the main channel to stabilize and eventually return to a meandering course. This is what happened to the Alpheios after c. 1900, which marks the end of a 1200 year cycle of hydrological disturbance that began with initial disequilibrium after 600 CE. In other words, even when response to unfavorable ecological behavior on the slopes became muted, the Alpheios was seriously maladjusted, eventually triggering a *secondary disequilibrium*, with cascading feedbacks documented as late as 1880. It would appear that continuing pastoral pressures did not allow the hydrological system to fully recover.

The first disequilibrium degraded slope soil, but the delayed secondary disequilibrium destroyed the larger and more productive floodplain. At some point in the Roman era it would have been a fertile bottomland, with a constrained, low-energy channel. During Medieval times the finer sediments and soil were abruptly swept away, to be replaced by a sterile expanse of bedload and ephemeral, shifting channels. This certainly qualifies as a serious economic and ecological impairment. The degree to which this non-equilibrium model (Table 1), modified in part after [20], applies to other medium-sized watersheds of Greece is currently unknown, but it has been observed elsewhere in the Mediterranean Basin, so in Catalunya, where the braided channels are called *ramblas*. The point of the model is to show how repeated disequilibrium can lead to progressively different consequences across many centuries, posing complex ecological problems that are not fully appreciated in the literature.

2.5. Discussion of land use and disequilibrium

The environmental history of the Argolid was not a linear trajectory towards degradation, but a complex alternation of change with intervals of stability, interrupted by episodes of ecological decline and recovery. Climatic inputs and prejudicial land use appear to be interwoven, while different histories of soil erosion and stream destabilization are documented by

Table 1
Soil erosion and stream alluviation: a non-equilibrium model

- *The stage is set* by quasi-cyclic intervals of **high climatic variability** and recurrence of **extreme precipitation events (EPEs)**, superimposed on periods with greater annual seasonal contrasts
- *Ecological change* is driven by **subsistence and/or social stress** as
  1. Population growth and food shortfalls favor short-term maximization;
  2. New technology carry "hidden costs" with ecological damage;
  3. Persistent sociopolitical instability militates against long-term strategies;
  4. Insecurity and war lead to short-term survival strategies;
  5. Immigration or invasion introduce subsistence information incongruous with local ecological experience.

↓

- *Changing ecological behavior* may impact **quality of land cover** by deforestation, cultivation of soils on steep slopes, or overgrazing so as to reduce canopy vegetation and ground cover.

In response there would be
1. Less infiltration of rainwater;
2. Increased and more rapid surface runoff;
3. Rapid and higher peak discharge in streams;
4. Less replenishment of ground water;
5. Reduced stream flow during dry season;
6. Atrophy of channel wetlands.

↓

- **Initial disequilibrium** is preconditioned by impaired quality of land cover and triggered or accelerated by **EPEs** *in narrow valleys*

↓

- **Soil erosion** may be entrained on vulnerable slopes or unconsolidated sediments by
  1. Mass movements, overland flow and rill-erosion;
  2. Deposition of sandy or clayey colluvium on valley margin footslopes;
  3. Transport of excess sediment into streams by extreme floods;
  4. Accretion of flood silts and activation of channel bedload.

↓

- **Stabilization**, after ecological damage has forced a *relaxation of settlement pressures*, may allow partial *vegetation recovery*.

↓

- **Secondary disequilibria** can be triggered by subsequent, high-frequency **EPEs** if land use processes resume, so that:
  1. Channels are deepened to accommodate high flood volumes;
  2. With uneven channel gradients, continuing **EPEs** can lead to discontinuous, *entrenched channels* ("gullies").
  3. Such gullied channel segments can rapidly erode headward,
  4. To shoot splays of coarse sediment into the downstream channel;
  5. Eventually, higher-order channels in *broader valleys* can fill with *bedload*;
  6. If **EPEs** persist, high discharges no longer deepen channels but favor lateral channel expansion by floodplain undercutting;
  7. The end-product may be an aggrading channel environment with braided, ephemeral watercourses and sand or gravel bars.

↓

- Established *braided channels* in major streams have significant economic consequences by encroaching on fertile flooplains, reducing agricultural productivity, and changing perennial to intermittent streams. They can only be reversed by a radical shift of the climate regime or land use.

Fig. 2, for different sectors. This calls for a detailed, analytical discussion:

(a) Activation of streams in upland valleys of the Argive Plain before c. 5300 BCE may be unique in the Peloponnese and therefore attributed to pastoral disturbance by small Neolithic groups. If this is correct, it implies that population growth or high density is not simply proportional to soil damage and hydrological disruption.

(b) Prominent alluviation on the Argive Plain and of the Alpheios River at Olympia during one or more phases of the Early or Middle Bronze Age indicates strong floods and sustained discharge along axial streams, requiring unusual volumes of water. That argues for a climatic anomaly with recurrent, excessive precipitation events. Debris flows in the Southern Argolid at the same time can also be primarily attributed to climate or for that matter, earthquakes.

(c) But this interpretation is offered with the major caveat that, without "disturbance", forested hillsides in the subhumid Mediterranean lands are characteristically quite stable. Similarly, peak discharges in undisturbed forested catchments are relatively subdued (except for world environments prone to hurricane-induced "catastrophic" floods). As Table 1 makes clear, it is my considered opinion that, in this particular Mediterranean and Holocene context, excessive precipitation events are unlikely to implement rapid and significant geomorphological change *without prior impairment* of the land cover by direct or indirect human activity.

(d) Less extensive alluviation in the Argive Plain after 1250 BCE and debris flows at Messenia after 1190 BCE are likely to be a consequence of strong land use pressures during the Late Bronze, perhaps exacerbated by pastoral disturbance that continued after agricultural recession. Gullying in the Southern

Argolid and colluvial activity around the Argive Plain date to a time of economic decline and intense upland degradation, during the last centuries of the first millennium BCE.

(e) Two disequilibria at Olympia probably followed Slavic pastoral immigration from a climatically different environment, while debris flows in the Southern Argolid are attributed to new agricultural settlement after 1000 CE. Since neither argument is secured by hard causal linkages, both instances may reflect the same inputs and thus be penecontemporaneous.

(f) Where the dating of erosional/depositional events is reasonably good, the lack of close synchronicity seems to suggest that thresholds are unique to a particular, local land use history. Repetitive disequilibria in the Argive Plain versus a limited number of events at Messenia, Olympia or the Nemea Valley also relates to different thresholds, namely variations of bedrock, local topography, and watershed gradients, i.e., potential energy. But that does not preclude differences in land use histories.

(g) As a practical solution to a subjective concept, it is suggested that soil, slope and stream disequilibrium serve as a convenient criterion for ecological damage, but not necessarily biotic degradation. On the other hand, changes in biotic composition and structure that do not lead to disequilibrium might be characterized as "transformation", a more neutral term.

(h) The composite picture does not support high population levels as a primary reason for latent instability. Erosional damage was most widespread during the Bronze Age (five major events, whatever the cause), compared with only few episodes during the Archaic to Late Roman time range (actually one major event), when population was four times larger. In post-Roman times, erosion reappears in the record (two major events), but after populations had been halved or more. That suggests several possible explanations.

(i) When slope stability was initially breached, much of the soil and sediment in "storage" on slopes was removed, leaving only a thinner soil mantle for subsequent erosional attack. To some degree that will be true, but it may not be a "sufficient" explanation.

(j) Hypothetically, a negative experience with destructive erosion, whatever its underlying cause, should promote adaptive behavior, favoring more conservationist land use [15]. That cannot be proven or disproven in a prehistoric context. Suggestive, however, is that erosional events later than 600 CE appear to have taken place after partial or large-scale social/ethnic replacement, e.g., Slavs, Anatolians, or Albanians with different ecological experience in environments without a strong summer drought.

(k) The pollen and inferred land use evidence suggests a further key issue, that may have reinforced the two previous explanations, namely the inherent dichotomy of cultivation and pastoralism.

Lowland forest clearance may only have modest effects on soil stability, since slopes are mainly gentle on the plains. Opening of upland forests on steeper slopes is another matter. A progressive transformation of land cover from forest, to open woodland, to Mediterranean maquis, and finally to rudimentary phrygana will have serious repercussions as tree canopy, and then ground cover is impacted by clearance, biotic replacement, or deliberate burning. Percolation of rain waters is reduced, more soil is exposed to rainsplash and sheetflow, runoff is accelerated, groundwater storage is reduced, and both small and large streams flood quickly, with higher peak discharge, and greater erosive force [10, ch. 8] (Table 1). Built-in feedbacks intensify the process.

Agricultural land use in gently sloping lowlands may fluctuate in quality of care or intensity without major ecological impact. But if cultivation is extended to steeper slopes, which is plausible with expansion of olive groves or vineyards, repercussions can be serious. Unfortunately, the Lerna pollen record is mute as to whether slope cultivation was attempted. Ecological transformation of uplands by pastoralism is another matter, and it is implicated by the pollen evidence. That now introduces a range of *social questions*.

Was short-distance pastoralism practiced by a different social subset than the people who tilled the land? Was pastoralism tightly linked with the daily routine and subsistence practices of those primarily engaged in cultivation, e.g., did most farmers also run animals on commonage, or only a privileged few, and were the livestock tended by hired shepherds/goat-herders or by younger family members? That immediately introduces a new set of questions about access to and control of commonage, larger matters of land tenure, and the overarching political economy [33]. The pollen record cannot answer such questions, which must be clarified by the indirect archaeological evidence, written records and historical context, as well as ethnographic insights.

Here we come up against the true complexity of explanation. The empirical and inferential groundwork of biophysical processes and probabilities argued or critiqued in this inductive case study provides substantive evidence for long-term ecological transformation and periodic disequilibrium, in part as a result of direct or indirect human impact on the environment. It also is basic "evidence" that contradicts certain unwarranted conclusions of Grove and Rackham [37], viz. that biotic change was primarily a consequence of climatic change, that human impact on land cover only reinforced ongoing "natural" trends, that soil erosion was a result of global climatic anomalies, and that the significance of such erosion has been exaggerated, because soil that is removed in one area supposedly contributes to the improvement of soils downstream.

Theoretically informed empirical analysis, combined with a healthy level of reflexivity, is critical for an effective environmental history. But the materials presented here do *not* contribute to an understanding of human ecological behavior or cause-and-effect relationships. One option is to turn to intensification and disintensification, the impact of integrated market economies, and the sociopolitical constraints on rural decision-making. Various chapters of Cherry et al. [26] on the isle of Keos, or of Sutton [65] on the Southern Argolid, address such issues for the last 600 years or so, but these are mainly "outsider" constructions. But instead of such structural or hierarchical explanations, we will focus on cause-and-effect relationships by following up two convergent lines of social enquiry.

3. Alternative voices to understand historical ecological behavior

3.1. The growth of experience and understanding: elite views

A little known fact is that there is a large body of first-hand writings on ecological themes in the Mediterranean world, that is somewhat misleadingly characterized as "agronomic literature". It is at once observational, analytical, subjective, and prescriptive as to human behavior, and composed in Sumerian/Akkadian, Greek, Latin or Arabic. It spans two cycles of intensification, and directly informs about technological change, scientific understanding, the socioeconomic context of intensification, and the role of pastoralism in terms that transcend sociocultural boundaries [13,14].

3.1.1. Inferences from the classical agronomic writings

The existence of an agricultural calendar in Sumerian times [62, pp. 202–212] suggests that the sequential activities of the annual cycle long were part of a vertical transmission of information, across the generations. The laws of Hammurabi in regard to shepherds and their flocks [58, Laws 261–267; 78], and their Medieval echoes [11], argue that the rules of pastoralism were already embedded in Mediterranean common law. This implies that socio-ecological conventions were agreed upon to regulate mutual agropastoral responsibilities, conflict, and cooperation as early as Neolithic times, as often as they may have had to be renegotiated. In turn the Classical literature on agronomy helps to illustrate processes, refinements, or new understanding across almost a millennium, from 800 BCE to 100 CE. In a broader Mediterranean context this represents a hemi-cycle of intensification, in which individual authors fleshed out anonymous change with direct, human insights [13].

There was an ongoing discourse about the selection of crops and suitable soils that became increasingly refined. First there apparently was the standard, Mediterranean two-field system, alternating cultivation with fallow, "every other year". But successive authors recommended more beneficial rotations, with one or other legume, or plowing beans under. Eventually it was recognized that all legumes help restore soil fertility. Only on exceptionally fertile soils was perennial cultivation possible without such nitrogen-fixing interventions. An incidental comment by Theophrastus suggests that many such advancements in understanding were achieved by common farmers, through trial and error, rather than elite experimentation.

By the end of the period, discussion of diverse fertilizing agents moves from the incidental to Columella's extended paean on manure ([2], Book 2), including the perceptive comment that wise farmers "manure a hillside more heavily than a valley, because…the rains are forever carrying all the richer matter down to the lowland" (2.17.7). Not only is he explicitly describing soil erosion, but elsewhere he recommends terracing of freshly cleared hillsides prior to planting (2.2.8–10). These various examples indicate that both elite and rural understandings were incremental and cumulative. All other things being equal, agricultural practice would become more conservationist over time.

Another underlying theme of this discourse is the economics of farming. Country people are of course aware of work input and potential prices at market. But from Xenophon to Cato, Varro, and Columella the theme becomes a drumbeat, implying a shift from traditional risk-minimization strategies to optimization, and finally maximization of returns. The importance of market-demand becomes increasingly explicit, the kitchen gardens of Pliny ([59], 19.49–188) being expanded to the market-gardens of periurban Rome. Varro, Columella, and Pliny were actually aware of the social implications of agricultural commercialization, but were in part compromised in their disapproval by being part of the process. The small freehold farmer was being forced out of the action, setting in train unexpected feedbacks that presaged agricultural and economic decline. Some variant of this scenario presumably played a role in other cases of disintensification since the Late Bronze Age. Thus the agronomic writings open a window on the human dimensions of intensification, revealing some of the underlying dialectics.

Most of the Classical literature is uninformative on the role of pastoralism, despite its attention to veterinary science. The Roman emphasis is on improved stock-breeding, mainly cattle, presumably for meat and dairy products. The exception is Varro, who once owned large stocks of sheep in Apulia, and who distinguished flocks that were kept locally, and stalled in winter or at night, versus those driven from winter pastures in lowland Apulia to summer graze in the mountains around Reate (Rieti), some 250 km via public sheep-walks (*sirpiculos, sic calles publicae*) [42, 2.1.16, 2.2.7–12]. Whereas boys and girls tended local flocks, armed young men herded the transhumant sheep, with one shepherd for every 60–100 animals, and flocks of up to 1000 head; most shepherds appear to have been slaves, but the head shepherd was expected to keep written records [42, 2.2.11, 2.2.20, 2.10.1, 2.10.10–11]. Varro notes that although the Roman people had sprung from shepherds, the skills and knowledge of the farmer and the herdsman were not the same [42, 2. intro. 5, 2.1.6].

This is the earliest, unambiguous contrast of local, short-distance pastoralism versus long-distance, seasonal transhumance, on the scale of the Spanish Mesta [11] or its Medieval Italian counterpart. It also identifies long-distance shepherds as "outsiders", in the employ of wealthy owners like Varro, unrelated to lowland villagers. Ecological behavior by pastoralists was therefore not necessarily consonant with the conservationist goals of villagers engaged in local transhumance. That has potential implications for biotic transformation of the Argive uplands, thus during Hellenistic times or when intrusive pastoralists such as Slavs or Albanians dominated the hills before settling in and intermarrying with long-term residents.

The Graeco-Roman agronomic literature, despite its schizoid conflation of estate-owners and smallholders, created a durable stereotype of the "good" farmer, as a repository of traditional virtues and model civic probity. In other words, "good" farming was a civic responsibility, and anchored squarely in the secular realm, and not a religious precept or theological imperative (as claimed by [69]). The land ethic of Greece and Rome was explicit, but secular.

3.1.2. A shared, cross-cultural experience

There also was an Islamic tradition of agronomic writings [14] that underscores the ecological and intellectual unity of the Mediterranean world. The roots of this literature were translations of Graeco-Roman works into Arabic, in part via Syriac intermediate editions. A novel Islamic tradition was launched by Ibn Wahshiya (c. 930 CE), an erudite Mesopotamian doctor, well-versed in medical botany. His massive but rambling treatise uses multiple sources, disguised by allegorical pseudonyms, in an effort to (re)create an indigenous Mesopotamian ("Nabataean") agronomy, based on Classical, Syriac, and Persian precedents.

This rich work became a leaven for a new center of agronomic writing and practical research in Southern Spain, where a Late Greek source had already been translated and emended shortly before 1000 CE. Subsequent Andalusian authors had access to both Ibn Wahshiya and an increasing number of Graeco-Roman works in translation. This culminated in the magisterial work of Ibn Al-Awwam (c. 1160 CE) [28], which synthesizes both, but is heavily grounded in a century of fresh Hispanoarab observations. Al-Awwam in effect revived the Classical agronomic genre, and his 1890 direct or indirect citations serve as a summation of 1500 years of Mediterranean agronomy. He integrated Eastern and Western, Islamic and Classical traditions, and commonly goes well beyond the last, such as in his comprehension of agricultural soils [14, pp. 29–35] or the sophistication of horticultural practices.

Unlike their Roman counterparts, the Hispanoarab agronomists were neither independently wealthy nor politically powerful, but worked as professionals connected with botanical gardens and agricultural projects or experiments. The Hispanoarab research was also recognized and valued in Christian Spain, with one work of c. 1090 CE translated into Castilian c. 1300; most of the Hispanoarab authors were in fact cited in a Spanish agronomic text of 1513.

For our purposes, the significance of Islamic agronomy is its intellectual continuity with Greek, Roman and Sasanid (Persian) observations or experience. Despite cultural and linguistic barriers, the subject matter and ecological appreciation were one and the same, with minor differences in the repertoire and changing priorities. Like their Roman counterparts, the Hispanoarab agronomists were devoted to agricultural expansion and mark the cusp of another intensification cycle, aborted because of the political collapse of Islamic Spain, during a turn to Islamic fundamentalism.

3.2. Negotiating concepts of "good" and "harmful" ecological behavior

We now switch time and scale, from an elite and cross-cultural discursive terrain to the ethnographic "present", focusing on an historical community study that Elisabeth Butzer, Juan Mateu and I carried out in eastern Spain across a span of seven years. It attempts to articulate village "voices" and rural ecoscience, to provide insights that can be compared with the agronomic literature. It also reveals the fine grain of community decision-making and how it impacts the environment.

Some 50 km north of Valencia was a cluster of small Muslim communities among the rough mountains of the Sierra de Espadán. First settled in the 11th century CE, they came under Christian-Aragonese rule in 1242, until they were uprooted and expelled in 1609. The social history of these villages is in part revealed by our archaeological excavations, in part by archival study [19]. After lying waste for a few years following the Muslim expulsion, the area was resettled by Christian families from adjacent parts of the region. But the colonists numbered only about 40 percent of the people displaced, so reducing pressure on the land, and resetting the ecological clock. Villages were rebuilt, but irrigation was taken over without change, and the inherited orchards remained largely intact. Land use change and ecological behavior from 1612 to the present was documented from extended searching of fragmentary archival sources and ethnographical enquiry [12].

These two periods represent quite different ecological experiences, raising basic questions as to explanation. I begin with the younger time span, focusing on the Christian village of Aín and its neighboring settlements.

3.2.1. Ecological ethnohistory in Christian Aín (1612 to the present)

The land belonged to a powerful magnate, the duke of Segorbe, and was held in permanent leasehold. A system of feudal restrictions and dues was inherited from the Medieval era, and the founding charter provided minimal financial incentives for land improvement, so that wheat was initially only planted on the best, irrigated land. Population began to grow during the 1690s, but then stabilized for a generation in response to war, drought and disease. Documents referring to terraces in 1686 and 1731 tell of agricultural expansion. Population growth accelerated after 1760, and the age–gender–marital status composition indicates a strong, voluntary curtailment of growth, presumably in response to land shortage. But agriculture in 1794 was flourishing, and a forest census of 1780 indicates a similar degree of tree cover as of about 1930. Yet the wheat supply was fragile, with sales and purchases at market in different years, indicating periodic shortfalls.

Under the feudal regime, woodland and other commonage belonged to the duke, and even dead wood could only be removed for a fee, effectively protecting the forest. The villagers could only keep limited numbers of animals, because annual transhumant grazing was under contract between the duke and the owners of large flocks of sheep from distant Aragón. Since the sale of leaseholds required the duke's permission and was relatively costly, there was no internal property accumulation.

After three decades of litigation, the villagers purchased their freedom from the duke during the 1830s and 1840s, with notable economic consequences. Olive groves were expanded, cork oak was replanted, and Aragonese flocks were reduced to 400 head, with four shepherds, to allow growth of local livestock. By century's end, six wealthy villagers ran 260 sheep and 140 goats, in part tended by outside shepherds. Population growth followed but stabilized within a generation; it began to decline during the 1880s, without emigration, as a result of birth curtailment since the 1850s.

During the 1860s the French vineyards were being destroyed by phylloxera, creating demand for Spanish wine. In Aín makeshift vineyards were greatly extended, even to the mountain crests, as woodland was reduced by 60 percent. However, rough terracing of the vineyards and tight control of the herds avoided detectable soil erosion. The unprecedented influx of capital made some farmers wealthy, allowing them to buy up property, so that by 1930, 6 percent of the landowners controlled 35 percent of the land. This did not undermine village solidarity, but the grown children of poorer families began to migrate as domestic maids or industrial workers to Barcelona during the 1890s.

The spreading phylloxera reached Aín in 1907 and the wine boom turned to an economic bust. Oral testimony of the oldest men explicated how destruction of the vineyards provoked seven years of community discourse that focused on three alternative solutions: (a) Expansion of pastoralism beyond the municipal boundaries; (b) Large-scale planting of cork oak, which would begin to provide good profits after 12 years; or (c) Emigration of the young people to the coastal cities. Under the guidance of progressive and well informed town fathers, the council eventually decided for the painful, long-term solution, and the area of cork oak was trebled and pastoralism restricted on communal land. But the cork market collapsed and massive out-migration accelerated.

From 1895 to 1930 an average of six young people were lost each year. The population fell from 522 to 167 during the years 1877–1981, while the percentage of people under 20 years of age dropped from 44 to 15. Every possible adjustment was made to changing regional, and later, global markets. At first, almond trees were planted in old olive groves, then cherry and apple trees appeared on irrigated land once reserved for wheat. Wheat farming was abandoned by 1960, and pine saplings have invaded former terraced fields and orchard groves. Local schools were closed.

Brought to the brink of extinction by a century of community devolution, Aín did not die, because of the tenacious loyalty of its people. A third and fourth-generation diaspora of out-migrants remains networked in Valencia and Barcelona, and pays taxes on ancestral homes. Middle-class men come up on weekends to work symbolically in the fields. Old houses are gentrified as vacation spots. Adults living in adjacent cities gather for Saturday-evening common meals, as their small children play together in the plaza, so that "they will learn to know who they are". University students bring their friends up on weekends, to reaffirm their attachment to place. And the outside observer is repeatedly reassured as to the traditional harmony and cohesion of the community.

These 400 years of socio-ecological history of Christian Aín elucidate a remarkable sense of community, attachment to home, and a pride of place, with strong esthetic overtones. Sound ecological behavior is implicitly expected of each individual, and is understood to be imperative for social continuity. Trees are explicitly cut down at a rate consonant with natural replacement. Thorny Mediterranean shrubs and brush once were regularly burned, under controlled conditions; now that burning is prohibited, the villagers complain that orchards and former pasturage are being overgrown. Land use changes since at least the mid-1800s were made in the light of extended community discussion and with reference to both community integrity and the market economy. Growth was regulated by population curtailment, with out-migration considered as an alternative of last resort. Terrace excavations and study of the alluvial valleys show that there has been no discernible soil erosion since the 17th century; in fact the main stream has incised its bed because of sediment starvation [21]. *This may not be an ''ecology'' palatable for idealistic modern environmentalists, but it explicates a traditional, practicable sustainability, closely tailored to a fragile Mediterranean environment.*

3.2.2. Repeated landscape disequilibria in Eastern Spain

This picture of environmental stability, evolving land use patterns, and market adaptation in the Sierra de Espadán, across the last 400 years, has to be put into context before addressing the divergent ecological experience of the cluster of Muslim villages in the sierra. To do so the earlier environmental history of the sierra is highlighted and contrasted with that of the coastal plain, which had a different settlement history. Environmental processes also played out differently within the sierra, depending on whether focus is placed on the alluvial history of the main, axial stream in the Sierra de Espadán, or on the hillsides of several valley segments.

Fig. 3 synthesizes some five millennia of soil formation or erosion in the sierra by means of two temporal columns that, prior to Medieval times, are only dated approximately by archaeological associations. Vegetation inferences are not based on a detailed pollen core, but spectra from different sedimentary units ([21,17]; Louis Scott, pers. comm.; [32, pp. 71–75]).

A first disequilibrium of the stream hydrology is indirectly linked to quite light Chalcolithic (proto-Early Bronze) settlement on the floodplain, when permanent flow was altered to an episodic, torrential stream, as based on changing molluscan assemblages. A closed pine forest in the vicinity was rapidly changed to oak or phrygana, presumably in response to deliberate burning. Thereafter a significant soil formed and the hydrology recovered, but the vegetation did not fully regenerate, probably evolving to an open pine-oak woodland.

The second disequilibrium of the axial stream came at a time of fairly heavy Late Bronze settlement in the basin, after a date of roughly 1650 BCE on aquatic snails. Strong floods and torrential alluviation resumed, and land cover was transformed to oak steppe/phrygana. There was partial recovery in the system as the area was partially abandoned, only to be again impacted by higher energy peak discharges, at a time of Iberian presence, perhaps continuing into the Roman period. During early Medieval times forests of *Pinus sylvestris*, now only found above 1600 m in the sierra, recovered, as verified by abundant charcoals from Beniali (see Fig. 1), identified by W. Schoch (pers. comm.). These are present as ''old'' wood, charred in the 1526 destruction of the site. A range of ^{14}C dates on such charcoal from 15th and 16th century levels falls between the late 800s and early 1000s CE. Woodland reconstitution was coeval with a distinct paleosol on the axial floodplain, impregnated and sealed by a younger calcareous crust. The original soil humates date ca. 900–1000 CE (cal. AMS date AA61796), which tie together the early Medieval woodland with soil stability.

A third disequilibrium is related to Islamic settlement, with accelerating alluviation dated by partial burial of irrigation devices [18]. After about 1600 the supply of soil sediment stopped abruptly, and finer material was stripped from the channel.

Two study areas contribute to the slope history column (Fig. 3). The Chalcolithic episode recorded in the floodplain sediments appears to have been localized. A shift from open pine woodland to mixed oak and pine may, however, relate to subdued land use changes, prior to the abrupt rupture of slope equilibrium at one site, directly linked by pottery to Late Bronze activity upslope (Alcudia de Veo; [21,32, pp. 71–75]). Grazing pressures apparently kept the slope vulnerable and covered by oak steppe/phrygana until perhaps Roman times, after which it was stabilized by soil formation. Intensive agriculture and disturbance are evident during Muslim occupation, until Christian resettlement and terracing. At another site (Beniali; [19]), emplacement of a new, mountain hamlet (1340s) first provoked soil erosion, which accelerated and then declined after temporary abandonment (c. 1362–1410), with incremental soil erosion continuing during subsequent reoccupation, until 1526.

The sierra columns (Fig. 3) show that soil erosion was widespread during only the second half of the Muslim settlement record. Late Bronze disequilibrium did not effect all areas, despite its incisive impact at some locations and a lingering role. The two major soil horizons of Fig. 3 are roughly contemporaneous, to the degree that they form stratigraphic markers for post-Late Bronze and early Medieval times. There may be one, two, or even three disequilibria, varying from one location to another, which underscores that direct settlement impact is important in defining different thresholds of equilibrium.

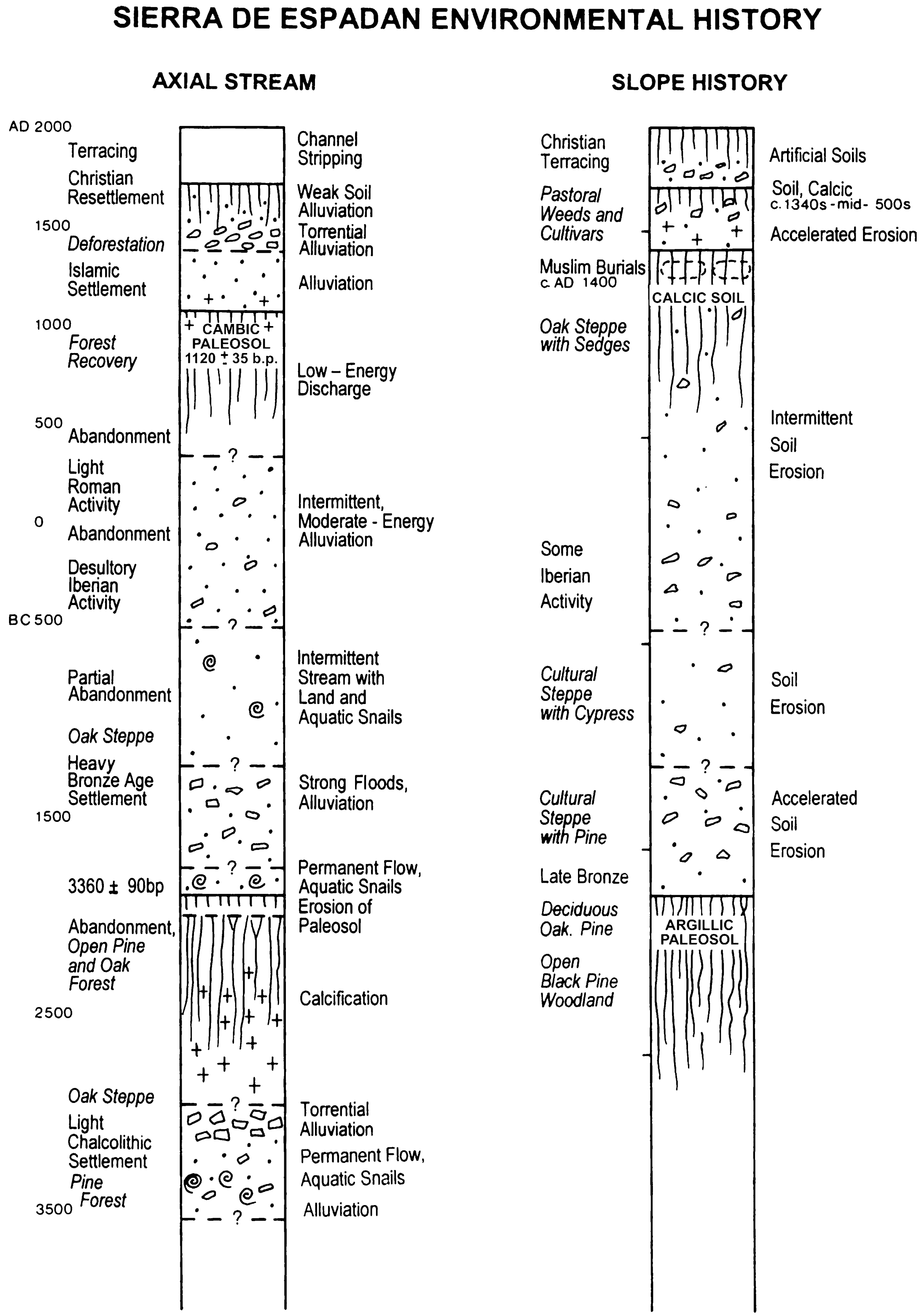

Fig. 3. Environmental history of the Sierra de Espadán in eastern Spain. The left column shows "events" such as geomorphic change, soil formation, accompanying vegetation types, and archaeology along the central stream. The right column gives a similar composite time line for several slope sites in the same valley. Both columns are proportional to time, not the thickness of sediments or soils. Pollen spectra for axial column after Louis Scott, unpublished; for slope column, after [31]. For explanations and other sources, see text.

Fig. 4 presents the simplified geoarchaeological record of two major rivers, the Turia at Valencia and the Júcar at Alcira. Both reflect disturbance across large watersheds that extend from the coastal plain into the mountains. A well-dated pottery sequence within the substrate of Valencia indicates a first disequilibrium at the beginning of the Common Era, with a minor resurgence of strong floods towards 700 CE, followed by a prominent floodplain soil; charcoals recovered from excavations record a shift of the major, available wood taxa from live oak, to olive, and finally steppe-pine [23,24]. A second disequilibrium is dated to c. 1100 CE, after which the environmentally sensitive parts of the city, near the channel, were permanently built over.

In the case of the Júcar River there is no visible record of Roman-era disequilibrium, but by 1100 CE, the watershed appears to have been progressively disturbed, leading to ever stronger floods in response to periodic clusters of extreme precipitation events, until the 1500s [22]. Thereafter floodplain modification interfered with the hydrological system, creating a latent instability with respect to excessive floods [54]. The similarities and differences between the records of Figs. 3 and 4 are illuminating. Major human impact in prehistoric times was localized in highland areas with settlement. During the last century BCE, the Romans resettled the indigenous peoples on the coastal plain, limiting land use in the mountains. The impacts of Islamic settlement expansion and population growth appear to begin a few centuries earlier in the large watersheds than in the Sierra de Espadán, where disequilibria were only reached after a secondary demographic expansion in the early 1300s. All these mountain environments were minimally settled during the first three centuries after the Arab conquest of 711 CE, allowing for contemporaneous soil formation and different degrees of forest regeneration. Changes of land use *do* matter.

3.2.3. Deleterious Muslim land use in the Sierra c. 1100–1609?

Within this empirical framework the question of Muslim use or misuse can now be examined and discussed. What we know about the 150 years or so prior to 1242 is based on our excavations in two Islamic refuge castles, and their archaeobotanical remains (W. Wetterstrom, pers. comm.) and animal bone (R.G. Klein, pers. comm.). The charcoal from the castle of Aín is almost exclusively that of woody shrubs (Kermes oak and maquis/phrygana elements) and the cuttings of orchard trees (plum or almond), with some cork and only traces of pine, elm and popular. That can be alternatively explained by (a) a steep, rocky hilltop location, (b) an interdiction to the felling of trees, or (c) a "degraded" maquis/phrygana vegetation. Charcoals from the castle of Xinquer, more distant and higher in general elevation, consist primarily of deciduous oak and orchard cuttings, with inconsistent representation of Kermes oak and maquis/phrygana taxa. The cuttings at both sites probably represent kindling, and the differences between the records of the two sites argue against a phrygana interpretation (c). Although goat is the dominant animal at both sites, cattle are also important. This confirms the lack of an early, Islamic erosional record in the Sierra: the biotic environment prior to 1242 had not yet been transformed.

The first settlement at Benialí (c. 1342–1362) has charcoals of plum/almond, poplar, olive and elm, but not Kermes oak, and only limited phrygana taxa (identified by W. Schoch). This does not suggest a transformed vegetation, even though the dominant livestock was goat and soil erosion was active. Our work at a contemporary Muslim cemetery exposed large numbers of seeds of weeds and flowers, washed into burial cavities, including *Chenopodium* (J.R. Harlan and D. Bedigian, pers. comm.). The charcoals and seeds suggest no more than localized biotic transformation. The soil erosion features at Benialí are also qualified in that 90 percent of the eroded soil sediment postdates site abandonment after 1362, i.e., there was some erosion during site emplacement on a steep slope, but apparent destruction of the site in a war situation presumably ruined the terrace walls, setting off a wave of erosion.

Only during the second occupation of Benialí (c. 1410–1526) did the vegetation change, with charcoals of almond/plum/peach and pine (2 species) dominant, no Kermes oak, and minimal phrygana elements; elm and poplar were no longer present. Over 90 percent of the 2250 animal bones identified belong to goat (R. G. Klein, pers. comm.), but the people primarily were Mediterranean farmers, cultivating durum and bread wheat, sorghum, an oil seed and broad beans, while also growing olives, almonds, peaches and figs. Limited quantities of soil sediment washed through the site after excessive rains, but the environment apparently was not deforested. Only in 1570 does the description of the sierra landscape by a commissioned Italian officer paint a treeless environment, in which even woody shrubs were scarce [19, p. 346].

In other words a blanket indictment of Islamic/Muslim land use as destructive is unwarranted. Closer examination shows that transformation was cumulative, despite the importance of goats, and soil erosion was situation specific. Only during the final three or four generations of Muslim persistence in the sierra was the last woodland cleared and soil removal more universal. There was more pressure on the environment than in Christian Aín, but disequilibrium thresholds do not appear to have been crossed until after 1300. Contrasting land use performance between Muslim and Christian villages such as Aín is more nuanced than a simple black-and-white dichotomy that might be suggested by

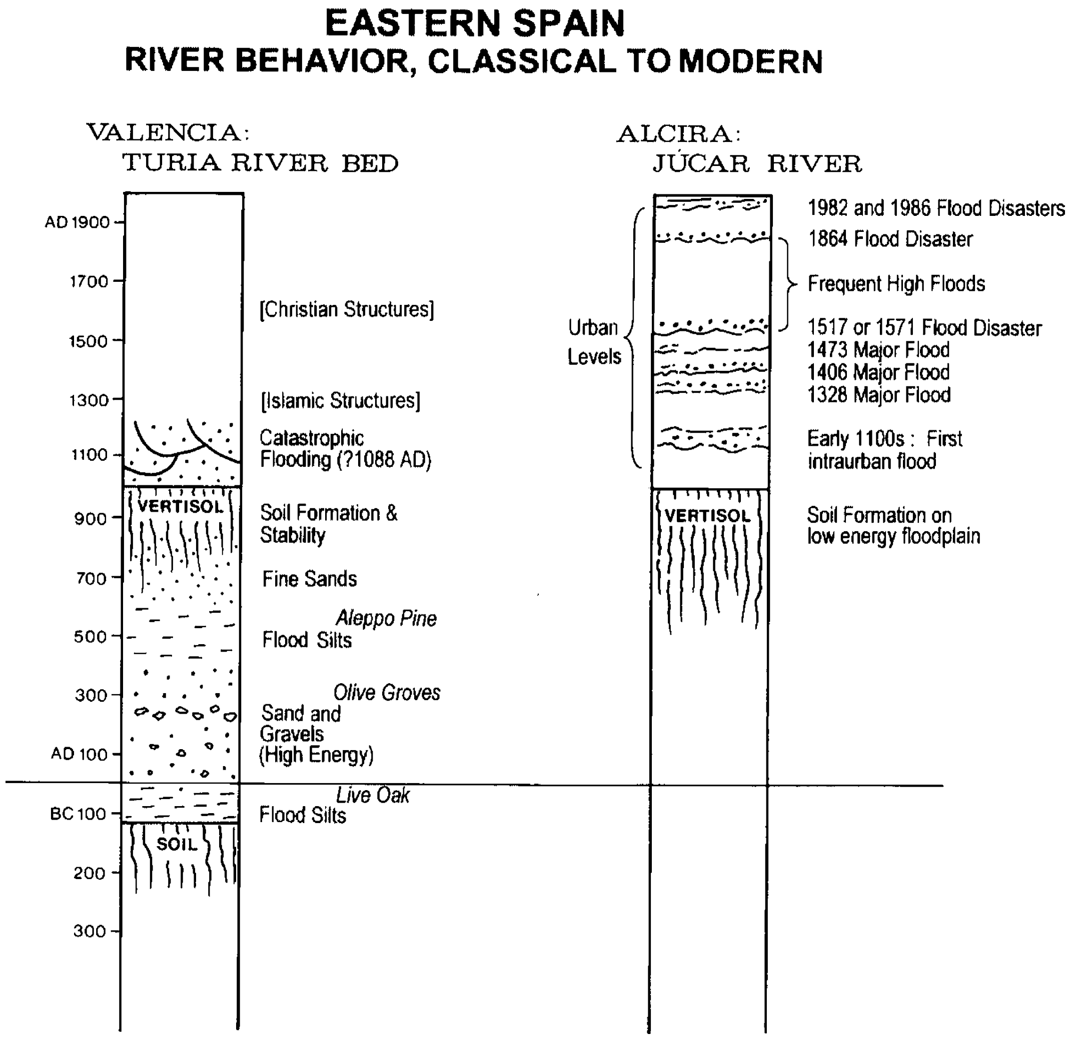

Fig. 4. Time lines for environmental change of the Turia River at Valencia and the Júcar River at Alcira, using similar conventions. For explanations and sources, see text.

the macro-scale record of the Turia and Júcar watersheds (Fig. 4).

But the basic question remains: Why the difference? The terms of the surrender document of 1242 for the sierra specified adherence to Islamic custom, and since the new contract of 1612 invoked prevailing custom and hereditary principles, we must assume that the rules in regard to woodland and role of transhumant versus local pastoralism will have remained much the same. That is also supported by documents on grazing privileges from 1321 and 1426. The answer must instead be sought in historical processes between 1242 and 1609 [19].

(a) Demographic growth is indicated by the founding of new hamlets such as Beniali c. 1320–1350, but a progressive decline or abandonment of satellite settlements after 1420 points to decline, with radical population loss after a failed revolt in 1526. From then up to the eve of expulsion, the Muslim population increased steadily to the level of 1421, which was similar to that of the Christian villages late in the 1700s. The documents verify *food stress*, thus unpaid debts on large purchases of sorghum, barley, millet and beans from the market in Onda in 1417 or again in 1500. Female goats at Benialí were slaughtered too early for optimal reproduction, suggesting a population living close to the breadline and heavily dependent on meat (as food or barter) during repeated times of food shortage (R.G. Klein, pers. comm.). In fact, ducal revenues from the grist mills and butchery show that more animals were slaughtered during years when milled grain was below average, i.e., harvest shortfalls.

(b) Whereas fixed taxes, rents, and tithes on produce amounted to a third of the annual income of an average farmer during the early 1400s, "special demands" were made every few years to support royal ambitions, including amounts equal to 5 or even 10 times the regular annual revenue obtained from the sierra. Fiscal demands in other words were *exorbitant* and ruinous.

(c) Political *instability* was a consequence of periodic Muslim revolts or war between Castile and Aragón that inevitably led to bloody repression as well as an erosion of community privileges. Attempted forced conversion during the early 1520s led to wholesale revolt in 1526, after which as many as 2000 men, women and children were slaughtered. In addition to the increasing *insecurity* of the countryside by 1450, with a continuing series of robberies and murders, the sierra communities after 1526 were disarmed, Quranic books burned, and the inhabitants forced to submit to evangelization.

Contending with demographic growth, limited resources, tax extortion, and deepening poverty, the Muslim communities were increasingly demoralized. Castilian campaigns across the sierra in 1362 and 1429 led to destruction, forced conscription, or reprisals. Forced conversion was the last straw, provoking a desperate revolt that left harvests in ruins and satellite villages abandoned. Their leaders killed and mosques destroyed, they now had to pay a new range of church taxes. *The "captive" Muslim population had little incentive to pursue conservationist strategies and focused on short-term survival.* After Christian mobs destroyed the Muslim quarter of Valencia in 1455, reconditioning of castles in the unruly sierra met passive resistance by the labor conscripted for the task. It is our contention that a similar passive resistance (see for example, [64]) after 1526 rendered the duke's bailiffs ineffectual in a hostile countryside, and thus unable to control destruction of the surviving forests.

Critical is that deforestation and soil erosion were the consequence of a sociopolitical pathology that undermined community solidarity. It did not demonstrably involve a shift to pastoral exploitation, and transhumant pastoralists had nothing to do with it. This may explain why biotic deterioration and destructive land use have been particularly common during periods of disintensification, often coinciding with what macro-history identifies as political devolution. Pastoralist migrations may contribute to such processes, but they probably are not an essential component.

The Christian villagers of the sierra were not "better" farmers than their Muslim predecessors. But they were fortunate in that their sociopolitical structures remained stable, at least until they were drawn into the boom-and-bust cycles of an internationalizing market place. Even then, their community solidarity survived, so that the sierra could remain alive through the cohesion of its diaspora. For the Muslims, eventually expelled under the most brutal circumstances, that never was an option.

Ecological behavior is contextual, and grounded in community experience and principles. All other factors being equal, such behavior favors continuity, even in dealing with stress or survival. This is a more complicated issue than simplistic, metaphorical interpretations of cultural and ideologically-driven land ethics [69,41] would allow. Religious elites may prescribe what already are traditional community values. But the common ecological thread is more a matter of social responsibility, which does not necessarily differ from one culture or religious realm to another.

4. Interpretive discussion

This critical examination of environmental change and ecological behavior emphasizes the contingencies to understanding, and the difference between process and "prediction". There are as many questions as there are answers.

4.1. A biophysical perspective

The select soil erosion/alluvial histories critically reviewed here illustrate *the problem of distinguishing change in response to climatic versus human impact*. Pollen spectra in the Sierra de Espadán indicate that soil erosion accompanied abrupt vegetation change during the Chalcolithic and again the Late Bronze. The hydrology recovered after this first impact but in at least some sectors the vegetation did not return to its original state. In the Peloponnese, a good pollen core provides the referent to off-site geomorphological work that elucidates slope and stream processes. Here an apparently localized but significant hydrological shift suggests Neolithic impact, whereas Early Bronze erosion and strong stream flooding in three study areas point to a higher incidence of extreme precipitation events in the 3500–1800 BCE time range. However, Late Bronze and other erosional episodes in the Peloponnese argue for a human impact, with or without reinforcing precipitation anomalies.

In other words, *the basic identification of and premises for anthropogenic disequilibrium must be grounded in hard-core biophysical research*. It appears that disequilibrium prior to the Late Bronze is more likely, but not always, to have been a result of climatic anomalies, whereas later events were more typically related to human disturbance, without however, precluding climatic factors in conjunction. This is a patently equivocal assessment. Given the contingencies of explanation, it is unwarranted in either the Peloponnese or Espadán to attribute specific episodes of soil erosion to one or other episode of global climatic-forcing.

There is no correlation between population density and the threshold of anthropogenic disequilibrium.

Very small Neolithic groups in the Peloponnese, or Chalcolithic ones in the Sierra de Espadán, had a significant impact on the environment, at some unknown spatial scale. Vegetation change was comparable to or greater than during the Hellenistic period in the Southern Argolid and Argive Plain. No such disequilibrium can be identified around Olympia, and perhaps not in the Júcar Basin either. Late Bronze to early Iron Age environmental impact was significant in most, but not all these areas. Late Roman to Medieval intervals of disequilibrium tended to be severe but perhaps brief, and they do not appear to have been synchronic.

The implication is that *problems with soil erosion cannot simply be retrodicted*. In part, this lack of correspondence between different drainage basins, large or small, would have reflected different thresholds due to topographic expression and initial soil thickness, and on which kind of slope and substrate. In part, it would have been linked to different patterns of land use or conservationist strategies/experience.

Mediterranean soils tend to be thin on slopes, and Holocene soil formation has been slow. There certainly has been cumulative soil erosion across much of the Mediterranean Basin during the last five millennia. The question is just how serious this has been for productivity. For the trained specialist the impacts of soil erosion are quite visible, since eroded soil and slope material collect on lower slopes and floodplains; but such areas represent only a fraction of a watershed. Jameson et al. [48, p. 193] argue that averaged out across the landscape, total Holocene soil loss was nowhere as great as it seems, and in the Sierra de Espadán the rate of Holocene soil removal was substantially less than that of during the later Pleistocene [21]. Mediterranean soils thicken or erode, naturally, across cycles of perhaps 100,000 years. That should not minimize the importance of anthropogenic soil erosion, but it opens a fresh perspective. For agricultural purposes, it is not so much the thickness of a clayey subsoil (B-horizon) that matters, but the degree of humification and stoniness of the topsoil. Humification does take place at a reasonable rate, within a few centuries, even if the subsoil does not thicken, and the manure from livestock is more critical for productivity than soil thickness. After Independence, the hillsides of Olympia were partly terraced and successfully converted to olive groves, on an unprecedented scale, on slope soils long eroded.

From the agricultural point of view, the supply of pastoral manure is more important than soil thickness. Thin Mediterranean upland soils, reflecting long-term geomorphic processes, have in the main part always been so. Dense, deep gully networks on the other hand are highly detrimental to agriculture, but these are uncommon in the study areas other than on a local scale. Soil and hydrological disequilibria imply a measure of degradation, but sustainability tends only to be threatened in restricted areas.

The significance of soil/stream disequilibrium is as much academic as it is practical. It helps to identify systemic response of the biotic and hydrological environment, and merits the designation of an ecological "crash". The pollen data show that land and ground cover in areas with palynological documentation have fundamentally changed since the Bronze Age. But woodlands were reconstituted during some periods of ecological reprieve, commonly with structural or floristic differences. When a closed woodland is transformed to phrygana, most professionals would agree that this qualifies as degradation. But there is a broad intermediate spectrum of modification or "damage" that is more difficult to characterize.

Disequilibrium therefore serves as a practicable index of serious land use stress on the biotic environment, and probably also identifies a threshold for degradation. But such impairments may be reversible, and need not affect long-term sustainability.

Commonly overlooked in sweeping generalizations is that ecological damage may well be local rather than regional, that is, only a few landscape components within a watershed may be affected. *The best diagnostic for extensive watershed damage in the Mediterranean is a trunk stream flowing in a broad braided channel, with sand or gravel bars extending across the width of the valley floor*. Such features are rarely discussed in the professional literature specific to soil erosion, despite their significance. But the Alpheios River demonstrates how, in a century or two, braided channels can be (re)converted to meandering streams. The nature of the channel, and its behavior during flood events, seems to offer the most sensitive record of changes in regional, as opposed to local ecology.

Contrary to popular deductivist assertions, environmental history should not be about how ecological damage is supposed to have happened, or when. *Cause-and-effect must be studied inductively*. "Change" is controlled by both biophysical and social inputs, as well as an array of feedbacks. Geoarchaeological and bioarchaeological study provides an indispensable foundation – but by itself is unlikely to reveal the cause-and-effect interrelationships of social and environmental variables. Natural science and social science must be combined; each theoretically informed but inductively engaged, with both vantage points working in complementary concert. Given the prevailing nature of subdisciplinary specialization, few researchers currently have the necessary individual skills for effective cross-disciplinary comprehension. At the very least, that demands more, honest interaction and less arrogance. In the longer term, it calls for a broader education of all varieties of environmental historians, and for an interdisciplinary research that does not privilege the social sciences over the natural sciences, or vice versa.

4.2. Human and social dimensions of explanation

At the heart of the "human" components that contribute inputs and positive or negative feedbacks are a range of cultural or social perceptions, and political constraints. The requisite research again requires breadth of vision and some modesty. A theory-driven social science approach is insufficient, as is readily illustrated by ongoing debates about the evaluation of local environmental knowledge, or competing positions on the role of political structures for environmental construction, conservation, and marginalization or control [60]. Such high-level debates are not readily applicable to a long historical frame. A more realistic premise is that *human perceptions and behavior are central to understanding cause-and-effect relationships*.

Several complementary approaches have been explored to tease out such humanistic insights. For one, the Greek and Roman agronomic writings open a remarkable window to show that: (a) ecological understanding among rural people was incremental and cumulative, and a product of trial and error; (b) the elite literature was cognizant of technological change as well as the social implications of agricultural commercialism and the underlying dialectics in regard to the human dimensions of intensification; (c) there were alternative strategies to manage livestock grazing by local, short-distance agropastoral mobilization versus long-distance, seasonal transhumance; and (d) the agronomic literature promoted a durable stereotype of the "good farmer" as a repository of traditional virtues and civic probity. The Islamic writings on this theme further demonstrate a cross-cultural continuity with Graeco-Roman observations and experience, despite the initial difficulties of "cultural translation" [14]. The Islamic authors were also engaged in agricultural expansion, but in the service of a progressive elite.

Switching from an elite, circum-Mediterranean perspective to a local, grass-roots counterpart, an ecological ethnohistory was reconstructed for a Spanish village of Aín in the Sierra de Espadán, pieced together from disjointed details in archival sources and by participatory ethnographic enquiry. Spanning 1612 CE to the present, *this rural and indigenous narrative reveals a constantly shifting repertoire of agricultural strategies in response to market opportunities, demographic growth, finite resources, and environmental problems*. In the absence of structural constraints, community resilience is displayed through flexible and adaptive decision-making. The village community and its diaspora eventually survived globalization and out-migration by a reaffirmation of its roots and belonging that has raised the ancestral village to ikonic status.

These ethnographic insights confirm the elite Graeco-Roman discourse on the good farmer, as articulated two millennia earlier: *"good farming" in the Mediterranean world was culturally embedded, as a civic responsibility* – a land ethic that was secular but no less explicit. Ideally, these sentiments would favor a traditional, practicable sustainability. The divergences from this norm are what require explanation.

The ecological harmony and stability of Aín after 1612 was not always the rule in earlier times. There is biophysical evidence for disequilibrium in the Sierra during the Chalcolithic and Bronze Age, and there was Roman disequilibrium in the large Turia catchment, with Islamic disruption after 1100 CE in both the Turia and Júcar catchments, following upon early Medieval forest and soil recovery. There is little more than conjecture to explain these early impacts, beyond a regional record of intensification in Roman and Islamic times. But after the Christian Reconquista in the 1240s there is considerably more information.

Islamic settlement in the Espadán began two centuries later than in the large drainage basins, but significant disturbance only began during the 1300s. There were no tangible differences in crops planted, irrigation practiced, or village-based goat herding from the 12th century to the Muslim expulsion of 1609. What did change was the sociopolitical context, as elucidated by the archival and archaeological record. Subjugated under oppressive Colonial rule, the restive Muslim minority suffered from food stress, tax extortion, insecurity, and increasing ideological repression. By the mid-15th century the Muslim population had neither opportunity nor incentive to pursue long-term strategies, focusing instead on short-term survival. It would appear that the tightening sociopolitical constraints and the massacre of 1526 eventually led to improvident decision-making and land use.

In contrast to the Christian resettlers, *the Muslim predicament underlines the significance of making or breaking of community spirit and solidarity*. At a higher level this relates to the measured and reasonably equitable give-and-take of what is called the "moral economy". I suspect that the intensity of Late Bronze degradation may also be about the breakdown of that moral economy, with attendant repercussions in the central lands under Mycenaean control.

Beyond the moral economy, the disruption or destruction of warfare or invasion merit emphasis. There are many possible scenarios. Slavic pastoralists settled in the Peloponnese, probably under warlike terms, and Greek settlement retracted to inaccessible or fortified sites. Christian Albanian pastoralists were brought in by the Venetians to maintain order as a paramilitary group, that eventually settled in countless villages which became linguistically Albanian. Muslim Albanian pastoralists introduced by the Turks behaved as a brutal soldateska, again leading to defensive, Greek settlement retraction. Was aggressive pastoralism the basic problem or was it foreign rule? Venetian domination in the Peloponnese and Cyprus was harsh and efficient, with Albanian mercenaries collecting taxes. Turkish rule was indirect and inefficient, at times leaving the Greek Orthodox hierarchy to farm taxes, and the mercenaries to keep control. *The common thread was fear and insecurity*, as is documented ethnohistorically for the Turkish period [34].

Whatever the administrative structures, we cannot ignore the oppressive or destructive role of foreign groups, with simpler forms of social organization, that can wield arbitrary power in the countryside when a distant ruling elite is weak, disengaged or exploitative, and a landed class is satisfied with short-term gains. Such intruders might well be drawn from agropastoral backgrounds, but as part-time mercenaries, raiders, or bandits they did not operate according to accepted social rules. If uncontrolled for decades or a century or two, their impact might well be a retraction or simplification of land use, demographic decline, and a degree of sociopolitical devolution. *Chaos and insecurity are powerful agents of disintensification*, as numerous other historical or more contemporary examples would illustrate.

The theme of warfare and invasion is usefully amplified by a closer look at the Mycenaean "collapse". It is not uncommon in Greek archaeology to discount the impact of the well-equipped groups of seaborne pirates known as the Sea Peoples. But there is solid written and archaeological evidence for their belligerence and capacity for destruction around the eastern Mediterranean basin, where they are closely linked with the breakdown of the integrated Late Bronze "world system" extending from the Aegean to Iran (c. 1220–1180 BCE, according to the Egyptian chronology) [68, pp. 91–99, 191–200]. Rather than suggest that the Sea Peoples destroyed Tiryns and Mycenae, it is plausible that a major raid, whether successful or not, combined with an earthquake and latent social instability as *a concatenation of crises, leading to sociopolitical simplification*. We recall the evidence that biological systems suffer serious ecological consequences when perturbations are compounded within the normative recovery time of a biotic community [55].

Given the importance of war, invasion or insecurity for disintensification, is it not possible that uncontrolled herders and their livestock could damage crops or wreak havoc on upland ecology? There are two different options to consider for pastoralism and livestock, one beneficial, the other destructive. We are well-enough informed about the "controlled" variant of pastoralism by literary sources and ethnography. As Forbes [33] emphasizes and Varro corroborates for an earlier era, short-distance, village-based pastoral activities differ from long-distance transhumance, managed and owned by outsiders. Transhumance was regulated under age-old rules grounded in customary law, with herders and owners liable for any damages. In Christian Aín, such herders lived in an exurb of corrals with their flocks and perhaps some family members. Transhumant herders were an integral part of local economies in that the annual accumulation of manure in the corrals or fields was essential for sustained soil productivity. In its various forms, the livestock sector was symbiotic with cultivation, rather than inimical or destructive. Goats, like pigs, mainly were household animals. Only sheep were transhumant.

Testimony about "uncontrolled" pastoralism is tantalizingly scarce because it was the exception to the rule, practiced by lawless outsiders or sanctioned by an exploitative landed class, alien or not. Clearance by fire, charcoaling, and uncontrolled grazing could transform upland vegetation, while constant depredations on standing crops can provoke agricultural abandonment. This could well be a powerful mechanism of ecological deterioration and disintensification. In the Lake Lerna pollen core, phrygana was characteristic c. 300 BCE–200 CE but there were no weed explosions; thereafter a more diverse maquis was re-established until the 9th or 10th centuries, with very high weedy readings suggesting abandoned farmlands. Exactly how this might relate to uncontrolled pastoralism is unclear, but it does suggest serious ecological problems of some sort. This time span includes the Slavic migrations, and thereafter conditions were not much better until Greek Independence. During the Middle Bronze, there was deforestation; but there is no case for biotic degradation being particularly salient during or immediately after the Late Bronze, despite the evidence for soil erosion. That advises caution about assuming pastoral interventions before or after the Mycenaean collapse.

Sustained economic growth is probably contingent on tolerable levels of human exploitation, combined with reciprocal assistance in times of need, and it presupposes social stability and security. Intensification in the guise of economic growth also is contagious, eventually affecting areas far beyond the direct or indirect control of a powerful polity, by creating demand and facilitating exchange. When systemic growth slows at the limits of a particular, available technology or when a lucrative exchange system falters, an elite may insist on more work from the productive sector but for lower returns; pressure on the land can mount, so that latent social and environmental instability would make the system vulnerable. A natural disaster, enemy attack, or revolt might even precipitate sociopolitical collapse. Such a scenario may apply to the Late Bronze Argolid.

4.3. Conclusion

Understanding cause-and-effect relationships in ecological change is difficult without an integrative and interdisciplinary methodology. The natural science information base is indispensable but insufficient for comprehensive explanation. Equally unsatisfactory are social science approaches, such as world-systems theory, heavily dependent on deductive economic and structural models. These are inadequate to explain environmental consequences, because they cannot anticipate the adaptiveness of human behavior and ecosystem resilience. Cause-and-effect in historical ecology is ultimately about real people, living communities and pride of place. Effective study of these attributes, and of how they may fail, requires more "insider" understanding of human behavior and less stereotyping. People are individual actors but also a collective pillar of resilience. People can and do adapt to uncertainty and change [5]. Sustainability in the long run will depend on them, not on vintage social theory.

The Mediterranean Basin today represents an endangered, rather than a devastated environment. Such a diagnosis is compatible with the environmental readings of a Goethe or a Monet, or the continuing streams of modern tourists and vacationers. But that diagnosis contradicts the Western protagonists of degradation, from Marsh and Huntington to the programmatic technocrats still making a business from "desertification" studies. Mediterranean productivity has been sustained across eight millennia of agricultural land use as a consequence of human and ecological resilience. The trajectory of Mediterranean environmental history consequently offers a rich record of diachronic experience for reflection and prognosis. Sustainability is a difficult, cognitive and empirical concept. A better appreciation and understanding will require integrative methodologies both within environmental history, as well as between the complementary domains of environmental and world-system histories.

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