13.4 Impacts of Early Agriculture and Deforestation on Geomorphic Systems

LA James, University of South Carolina, Columbia, SC, USA

Glossary

Anthropogenic geomorphology An emerging subdiscipline of geomorphology concerned with processes initialized or dominated by human agency.

Before Common Era (BCE) A time scale also known as Before Current Era or Before Christian Era. Used as nonsecular designation synonymous with Before Christ (BC). Begins with the year 1 BCE (the year before 1 CE) and increases back in time; i.e., 300 BCE is equal to 300 BC.

Before Present (BP) A time scale based on years before 1950 CE, the approximate time that radiocarbon dating became feasible. Although some scientists prefer to reserve 'BP' for reporting years based on radiocarbon dating, this article uses the term more generally for years based on a variety of geochronlogical methods.

Common Era (CE) A time scale also known as Current Era or Christian Era. Used as nonsecular designation synonymous with Anno Domini (AD). Begins with the year 1 CE and increases forward in time. The year 2012 CE is equal to AD 2012.

Geomorphic effectiveness The ability of processes or events to generate geomorphic change. Change may be defined in many ways including generation of landform features, persistence of features, or movement of sediment. In this article, geomorphic effectiveness is used in a general sense for processes that generate sediment or landform features. The relative geomorphic effectiveness of different agricultural systems can vary greatly between agricultural technologies, timing, climate, slope, soils, and vegetation.

Legacy sediment Earth materials - primarily alluvium - deposited following human disturbances such as deforestation, agricultural land use, or mining. The phrase is often used to describe post-European floodplain sediment, also known as postsettlement alluvium. Awareness of legacy sediment has grown in response to the importance it plays in sediment budgets, water quality, river

James, L.A., 2013. Impacts of early agriculture and deforestation on geomorphic systems. In: Shroder, J. (Editor in Chief), James, L.A., Harden, C.P., Clague, J.J. (Eds.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 13, Geomorphology of Human Disturbances, Climate Change, and Natural Hazards, pp. 48–67.

 http://dx.doi.org/10.1016/B978-0-12-374739-6.00342-0

restoration, toxicity, lateral channel connectivity, and geomorphic theory (James, 2010).
Neolithic cultural period The transitional period of human prehistory in which stone-age cultures began to develop agriculture, including domestication of plants and animals, land clearance, and sedentary lifestyles. This transition occurred independently on different continents at various times. The Neolithic transition ultimately ended with the introduction of metal tools.

Abstract

This synthesis examines agricultural development and potential geomorphic changes on broad scales of time and space. Anthropogeomorphic change increased with Neolithic agriculture. In Europe, substantial fluvial responses to deforestation began in small catchments during the Bronze and early Iron Ages and spread to larger rivers during the historical period. Pre-Columbian environmental impacts in the New World – dominantly ecological change – have been revised upward, but geomorphic change is not well documented. Rejection of the 'pristine myth' conflicts with common assumptions by geomorphologists that New World geomorphic conditions were relatively undisturbed until European contact. Pre-Columbian New World societies had much lower geomorphic potential than European colonists.

13.4.1 Introduction

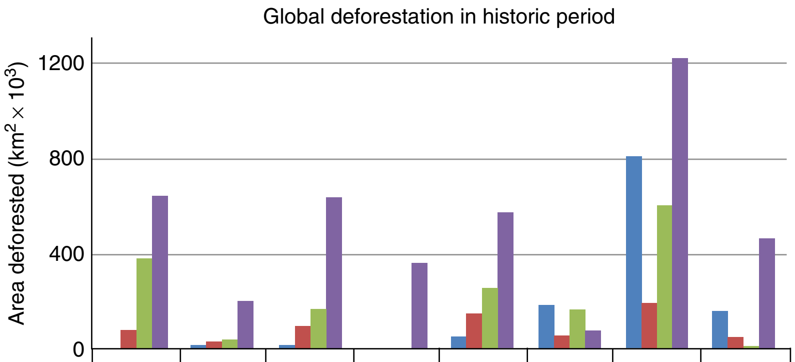
Mounting evidence corroborates the premise that anthropogenic changes in land cover; for example, conversion of woodland to agricultural land, changed or amplified responses of hillslope and fluvial systems to climate change over the late Holocene. Following the advent of agriculture in the Neolithic, anthropogenic soil erosion was primarily generated by grazing, burning, and land clearance for cultivation (Butzer, 1982; van Andel et al., 1990). Prehistoric and historic clearance and manipulation of land for agriculture included cutting, burning, plowing, and drainage of land. Accelerated erosion from these practices is linked to increased stream sedimentation and floodplain metamorphosis. Ultimately, the development of efficient land-clearing, sod-breaking, and timbering technologies in Eurasia, including domesticated draft animals, heavy plows, and mechanized sawmills, led to extensive clearing and, at various times and places, severe erosion and sedimentation. When these technologies were suddenly introduced to the New World through colonization, an episode of erosion and sedimentation often ensued. Colonization often led to erosive land use and episodes of erosion and sedimentation. Later, following the decline of agriculture in a region, reforestation commonly resulted in reduced water and sediment loads. Thus, the introduction and subsequent decline of agriculture in a watershed could result in an aggradation–degradation episode downstream that is documented in the stratigraphic record as legacy sediment (*see* Chapter 9.37). Hydrologic and channel responses to vegetation clearance and other land-use changes during the historic period are reviewed by Harden (*see* Chapter 13.2) who concentrates on large rivers, and Royall (*see* Chapter 13.3) who focuses on small catchments.

Great variations in anthropogeomorphic impacts through time and space are demonstrated by patterns of forest clearance during the later historical period (**Figure 1**). Most land clearance occurred after 1650. Areas of deforestation show striking variations in timing and magnitude between regions. Early and consistently high rates of deforestation in Asia explain, in part, high sedimentation rates in Asia. The late timing of clearance in most areas outside of Asia and Europe reflect the effects of clearance associated with colonization of the New World and Africa. An independent estimate of deforestation indicates that ~700 million hectares of closed canopy forest had been lost by the late twentieth century since the advent of agriculture, a global loss of ~15% (Matthews, 1983; Williams, 1990).

13.4.1.1 Goals and Scope of Chapter

This chapter examines the history and nature of early agriculture and the geomorphic impacts associated with land clearance, tilling, and erosion. It outlines the origins of agriculture in the Neolithic, and the spread and intensification of agricultural technology from the Middle East to northwestern Europe and ultimately to the New World. Evidence is examined for erosion and sedimentation generated by these activities. How Eurasian agricultural technologies developed the potential to be highly erosive is examined. When a high potential for land clearance was coupled with advanced transport technologies and export trade economies, the potential and motivation for land exploitation was unleashed. When and where these technological and economic factors were combined with the breakdown of land-stewardship practices and restraints, large tracts of land could be cleared rapidly with little regard to sustainable land management. Under these circumstances, land clearance could be extremely effective in initiating an episode of geomorphic change through severe erosion and sedimentation.

Agricultural land use is considered broadly here to include cultivation and deforestation. Although the geomorphic effects of domesticated grazing animals are not directly examined, those impacts could be intense and widespread. In some cases, the introduction of domesticated grazing animals accompanied cultivation, and the geomorphic responses to grazing and cultivation are inextricably intertwined. In other cases, grazing dominated a particular cultural group resulting in complex spatial and temporal patterns in which the impacts of cultivation and grazing may be difficult to separate. The four sections of this chapter follow a historical progression: Emergence of early agriculture, intensification, introduction of agriculture to the New World, and modern agricultural impacts.



	N. Amer	C. Amer	Latin amer	Oceania	USSR	Europe	Asia	Africa
<1650	6	15	15	4.0	56.0	190	807	161
1650–1749	80	30	100	5.0	155	60	196	52
1750–1849	380	40	170	6.0	260	166	601	13
1850–1978	641	200	637	362	575	81	1220	469

Figure 1 Estimates of areas of deforestation by global region for four periods. In all regions except Europe, deforestation has been greatest since 1850. Values were calculated as median values of high and low estimates tabulated by Williams, M., 1990. Forests. In: Turner, II B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (Eds.), The Earth as Transformed by Human Action: Global and regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge, UK, Chapter 11, pp. 179–201.

13.4.2 Emergence and Geomorphic Impacts of Early Agriculture

Geomorphic activity rates are highly dynamic. The effects of climate change and tectonics operating on threshold–response systems generate variable process rates through space and time. Thus, anthropogenically induced changes during the Holocene must be evaluated within the context of this high natural variability. In general, Pleistocene rates of sediment production and transport were greatly elevated by climate-change impacts, including glaciations, sea level fluctuations, and active aeolian and periglacial systems. This was followed by much lower rates of sediment production and transport during the Holocene. Thus, increased rates of geomorphic activity caused by late Holocene human land clearance were, on average, small relative to natural Pleistocene rates. Yet, human impacts were generally episodic and locally important, and they caused significant changes in the late Holocene stratigraphic record. In the Neolithic, human agricultural practices began to alter erosion and sedimentation rates substantially in places. As land-clearance technologies became more effective at disrupting land cover, the potential for geomorphic change tended to increase through prehistory and into the historic period, although geographic patterns of this potential varied greatly.

In many regions, the first substantial human impacts on environmental systems were caused by hunting and the use of fire (e.g., Rius et al., 2009). Before and during the transition to agriculture, hunting altered herbivore populations and grazing pressures (Martin and Klein, 1984; Cassals, 1984; Peters and Lovejoy, 1990). Although fire and hunting had substantial impacts on ecosystems before the introduction of agriculture, the geomorphic impact was far less than that of changes later in the Neolithic brought about by deforestation and cultivation. Specific inferences about the acceleration of geomorphic processes in response to vegetation clearance and plowing need to be tested with empirical data over these time scales by linking stratigraphic evidence of episodic erosion and sedimentation to processes of sediment transport. This task involves understanding the spatial–temporal complexities of long-term sediment dynamics and interactions between climate and land use. Sediment yields integrate all hillslope erosion and sediment transport processes in small watersheds as well as storage and recruitment processes to and from floodplains in larger rivers (Walling, 1983; Vanmaercke et al., 2011). Moreover, the spatial locations of storage and recruitment in a basin change over time (Walling, 1983).

This section describes the emergence of early agriculture, its spread, and the early evolution of Neolithic agricultural technologies. Two cultural centers, northern China and the Middle East, are used as diverse examples of the Neolithic revolution. The spread of agriculture into western Europe provides an example of how agricultural technology expanded from one of the centers and of the deforestation that ensued. The Neolithic transition is then described in the New World. Agriculture was not practiced on the Australian continent before the introduction by colonists during the historical period, so discussion of the impacts of Australian cultivation is deferred to Section 13.4.4.

13.4.2.1 Importance of Agriculture to Geomorphology

Agriculture can be geomorphically effective on a widespread basis, particularly when cultivation or managing livestock is coupled with deforestation or other forms of land clearance. Direct geomorphic impacts arise from increased runoff, erosion, and sedimentation initiated by land clearance and agriculture. Direct linkages between land use and responses in runoff, erosion, and sedimentation rates are well established. Over the long term, extreme examples of erosion associated with agriculture have resulted in loss of utility of the land. Lal (1988) estimated that the total loss of farmland due to soil erosion since the beginning of settled agriculture was 430×10^6 ha.

Indirectly, land clearance results in the release of CO_2 to the atmosphere, which increases greenhouse gases and climate warming. Postindustrial land-use changes contribute to climate changes that are associated with rising sea levels, glacial melting, and regional shifts in temperature and precipitation patterns, all of which have geomorphic consequences. A theory under debate is that anthropogenic land-use changes have had measureable impacts on climate since the late Holocene (Ruddiman, 2003; Vavrus et al., 2008; Ruddiman and Ellis 2009). More recently during the historic period, it has been argued that reforestation of Meso-America following a dramatic post-Columbian decline of indigenous populations, sequestered CO_2 from the atmosphere and contributed to climate cooling that corresponded to glacial advances in the Little Ice Age (Nevle and Bird, 2008; Dull et al., 2010).

13.4.2.2 Quaternary Sediment Yields

Anthropogenic increases in Holocene sedimentation rates must be considered against a backdrop of extremely high rates during the Pleistocene. Some geologic studies have assumed that modern sedimentation rates are comparable to long-term sediment production and denudation rates over geologic periods that can be inferred from marine stratigraphic studies. Studies that demonstrate or assume similar rates between Quaternary and modern erosion, denudation, or fluvial sediment yield rates are reviewed by Phillips (2003). If this correlation is valid, it would imply stable sediment yields over geologic time. Given that all weathered material produced in a watershed is either retained as regolith, stored as alluvium, or transported out of the basin, a dynamic stability of the sediment system could be maintained over geologic time spans if the alluvium remains available for transport and weathering rates are moderated by the accumulation of regolith (Phillips, 2003). Storage and recruitment of alluvium may tend to buffer sediment systems against environmental changes over geologic periods. From the perspective of Quaternary time scales, however, sediment yields to the world oceans varied considerably between the late Pleistocene and the Holocene.

Average Holocene sedimentation rates were higher than Tertiary rates, but lower than Pleistocene rates. Sediment production increased in the Pleistocene due to climate change and tectonics (Hay, 1994). Based on varves in cores, estimated average sedimentation rates in the Black Sea over the Quaternary period reached a maximum during the deglacial period, declined greatly, but increased substantially in the past millennium (Table 1). Over the millennial time period of concern for early anthropogenic change studies, fluvial sediment storage or recruitment may behave episodically, with dominant periods of erosion, sedimentation, or stability. This episodic behavior produces variations in the stratigraphic record that allow identification of past cultural and climate events. Late Holocene increases in sedimentation rates have been demonstrated by borehole data along Rhine River floodplains and terraces, where two- to three fold increases in rates were observed (Figure 2). That study found that floodplain sedimentation rates during the late Holocene were even higher in smaller tributaries, with between 1 and 1000 km^2 in drainage area, whereas increases during the Bronze Age suggest influences by human disturbance. Similar late Holocene increases in sedimentation rates have been demonstrated on the upper Mississippi and its tributaries (Knox, 2006).

Table 1 Quaternary sedimentation rates in the Black Sea (Degens and Ross, 1974; Degens et al., 1978; Hay, 1994)

Time period	*Rate*
^{14}C a BP	cm kyr^{-1}
0–1 000 BP	30
1 000–5 000 BP	10
Holocene	12
Deglacial period	1000
Quaternary mean	40

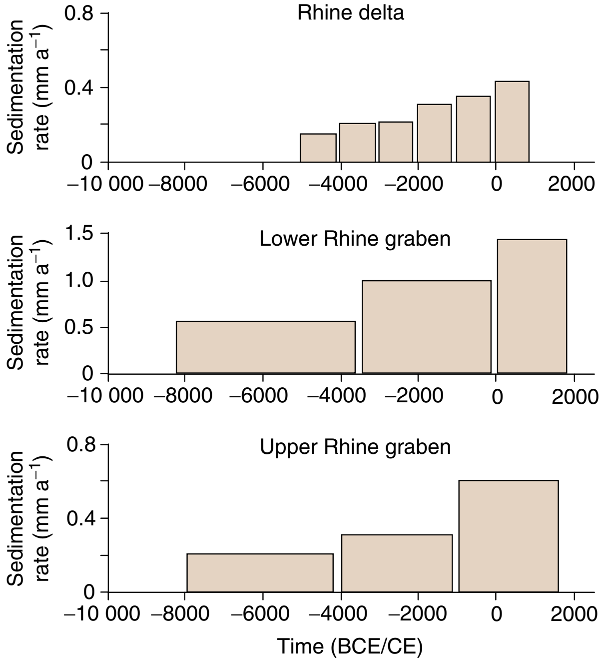


Figure 2 Holocene sedimentation rates on the Rhine River based on borehole data and radio carbon chronologies. Drainage areas (and number of boreholes or coring logs) are 185 000 km^2 (280) in the Rhine Delta, 155 000 km^2 (3501) in the lower Rhine Graben, and 70 000 km^2 (310) in the upper Rhine Graben. Adapted from Hoffmann, T., Erkens, G., Gerlach, R., Klostermann, J., Lang, A, 2009. Trends and controls of Holocene floodplain sedimentation in the Rhine catchment. Catena 77, 96–106.

13.4.2.2.1 The Neolithic

The transitional period of human prehistory associated with the adoption of agriculture and sedentary living, that is, the *Neolithic*, includes the domestication of plants and animals and clearing of forest lands. Definitions of the Neolithic transition vary and have included a cultural phase, set of cultural artifacts (the 'Neolithic package'), mode of production, specific migratory population, social structure, or time period (Price, 2000; Rowley-Conwy, 2004). The classic explanation for the Neolithic was that it occurred as a transition of hunter–gatherer groups, to pastoral nomadism, to agriculturalists. Pastoralism was considered a necessary intermediate step. Sauer (1952) traced this concept back at least as far as the Romans and credited Alexander Von Humboldt as the first to recognize that advanced agriculture developed in the New World without any form of pastoralism. Most modern scholars regard pastoralism as a marginal enterprise that occurs where agriculture cannot wholly sustain the group (Renfrew, 1987). In Eurasia, Neolithic farming was generally associated with domestication of large herbivores, but this was not a necessary condition and did not occur with the advent of farming in some other regions. The Neolithic is used here simply to designate the local time of adoption of agriculture without ascribing a particular set of processes by which that may have occurred in various times and locations.

Agriculture emerged independently in many diverse regions on most of the continents at various times during the Holocene, so the onset of the Neolithic is time transgressive as it spread outward from a given cultural center (Jones, 2008). Early agriculture developed in several centers including Mesopotamia in the Middle East, the Yangzte and Huang He in China, the Indus and Ganges–Bramaputra Rivers in south Asia, the New Guinea highlands, Egypt in northern Africa, the Andes highlands in South America, and Meso-America. The initial onset of the Neolithic was not a sudden event to which a single date can be assigned, but was a transitional process. Agriculture was initially developed by experimentation, that is, foraging humans began moving favored plants to advantageous locations and manipulating them, beginning a slow, gradual transition to cultivation and land manipulation (Flannery, 1969; Moore, 1982; Pringle, 1998). Knowledge of various agricultural practices outside of the cultural hearths may have occurred as a result of diffusion, migration, conquest, innovation, or combinations of these processes. In some cases, this spread may have occurred relatively rapidly as a result of migration or conquest of a region, but interregional expansion of agriculture ultimately involved intercultural exchanges over a period of generations.

The Neolithic was a time when settlements of increasing permanence began to be established. The sedentary nature of these settlements had several advantages that encouraged further technical developments and intensified land clearance. Hunter–gatherer societies were limited in what they could carry and generally relied on continued movement to ensure the availability of abundant plants and game. In some instances, abundant resources permitted sedentary cultures to develop without cultivation, for example, sedentary Mesolithic cultures in Europe (Price, 2000) and indigenous cultures in the Pacific Northwest of North America. Sedentary cultures generally required the cultivation of domesticated plants or raising of domesticated animals to ensure reliable food reserves at a given location.

Wherever agriculture began, it tended to spread gradually to arable lands. Ultimately, sedentary farming communities crowded out roaming groups of hunters and gatherers in habitable areas. As the Neolithic progressed in a region, intensifying agricultural land use was associated with increasing potential for soil erosion as populations grew and deforestation spread. Recognizing the impacts of Neolithic land clearance and agriculture is complicated by variations in climate, but general patterns concerning interactions between impacts of land clearance and climate change are beginning to emerge. For example, slope deposits tend to record local human land-use changes, whereas the alluvial stratigraphy of larger rivers tends to initially record climatic events (Houben et al., 2006; Dotterweich, 2008). An analysis of ^{14}C dates in Britain led Macklin and Lewin (2003) to conclude that changes in land use resulted in a sudden increase in sensitivity of river basins that left them vulnerable to changes in climate.

13.4.2.3 The Onset of Agriculture in North Central China

The climate in central China shifted from cool and dry to warm and humid in the early Holocene (BCE 9000–7000), allowing expansion of broadleaf forest in some areas and the initial appearance of sedentary villages in the Central Plains (Liu, 2004). Evergreen and broadleaf deciduous forests thrived during the Holocene hypsithermal (BCE 7800 to 2500) (Yi et al., 2003). Early Neolithic cultures first began to appear in farm villages scattered across the alluvial plains of central China, with the beginning of the Holocene climatic optimum between BCE 7000 and 5000 (Liu, 2004). The transition to farming was gradual, however, with hunting and foraging remaining dominant for a long period. The spread of agricultural groups in China corresponded with the extirpation of elephants (**Figure 3**). The expansion and intensification of the Neolithic in northern China coincided with a southward shift in the limit to the range of elephants (Elvin, 2004). The extirpation of elephants from northern China may have been caused by conversion of land use and displacement as postulated by Elvin (2004). Earlier Asian cultures had followed large pachyderms across the Beringia land bridge to North America, however, contributing to the extermination of many large herbivores there prior to the introduction of agriculture (Martin and Klein, 1984).

Slight cooling occurred from BCE 2500 to CE 700 and was accompanied by deforestation and other vegetation changes at *c.* 4 and 1.3 cal. kyr BP that are attributed, in part, to cultivation (Yi et al., 2003). Reductions in broadleaf forest and increases in pine *c.* 4 cal. kyr BP, and the first appearance of buckwheat pollen (*Fagopyrum*) at 1.3 cal. kyr BP are interpreted as evidence of intensive cultivation of dryland forests (Yi et al., 2003). Between BCE 300 and CE 100, a transition between dominance by hunting and foraging to dominance by primitive farming has been expressed as a shifting boundary in the Huang He basin of the Loess Region (**Figure 4**). Topographic relief was considerably less in the Loess Plateau before extensive erosion of gullies was initiated by cultivation in the region. Soils were relatively stable under natural vegetation, but experimental data indicate that crops

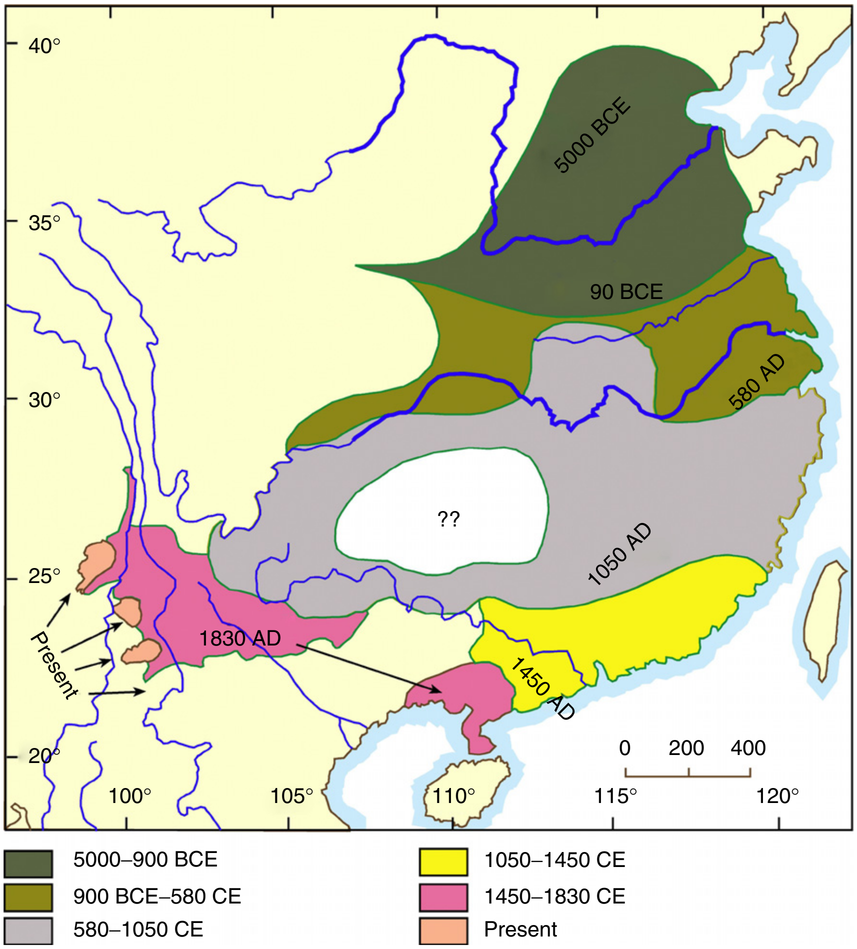


Figure 3 Extirpation of elephants in China from BCE 5000 to present. The removal of elephants from a region is indicative of extensive settlement and cultivation. Elephants had been in north China around the Huang He between BCE 5000 and 900 but only a small refugia remained by 1450 CE. Adapted from Elvin, M., 2004. The Retreat of the Elephants: An Environmental History of China. Yale University Press, New Haven and London, 564 pp. who derived the map from Wen Huanran, 1995. Zhongguo Lishi Shiqi Zhiwu yu Dongwu Bianqian Yanjiu. (Studies on Changes in Plants and Animals in China during Historical Times) Chongqing chubanshe, Chongqing, (Cited by Elvin, 2004).

growing on loess generate almost two orders of magnitude more erosion than under forest or grassland (Ren and Zhu, 1994). In prehistory, relatively flat undissected loess plateaus (yuan) were common. Many of these areas remained extensive up to the seventh and tenth centuries CE during the Tang dynasty but have since eroded severely (**Figure 5**).

Interactions between climate change and agricultural land clearance were substantial in China during the period of agricultural expansion. Owing to the cultivation of highly erodible lands, sediment deliveries from the Huang He to the Yellow and East China Seas have increased an order of magnitude from early and mid-Holocene preagriculture rates (Milliman et al., 1987; Saito et al., 2001) (**Table 2**). Historical evidence for clear-water streams indicates that tributaries in the Loess Region did not become silty until after cultivation was introduced, by approximately BCE 300 in the Jing He and sometime after the turn of the current epoch (>1 CE) in the Yan He (Ren and Zhu, 1994). Problems with flooding on the Huang He were sufficient to warrant the construction of dikes on the river, beginning between BCE 475 and 221 and increasing thereafter (Dakang and Peiyuan, 1990). In little more than one millennium, populations in the Loess Plateau grew approximately two orders of magnitude from 700 000 during the Han Dynasty (BCE 206–CE 220) to 60 to 70 million during the Tang Dynasty (CE 618–907) (Saito et al., 2001). The name 'Yellow River', derived from the high suspended sediment loads, was not widely applied to the Huang He until the seventh century CE (Tang Dynasty) (Ren and Zhu, 1994).

The Huang He Basin experienced two periods of accelerating sedimentation rates in the past 2300 years. Xu (2003) identifies three stages of sedimentation in the Yellow River, separated by pronounced increases in sedimentation rates between CE 600 and 1000 and after *c.* 1850 (Xu, 2003; cf. Figure 16 *in* Chapter 9.37). Comparison of Huang He sedimentation rates to a record of humidity over the past 2000 years indicates that sediment deliveries were not simply driven by climate (Xu, 2003). A rapid decline in moisture corresponded to a period of rapid aggradation during the Tang Dynasty (CE 618–907) and early Song Dynasty (CE 960–1279), periods that were associated with economic prosperity and rapid destruction of forests for wood

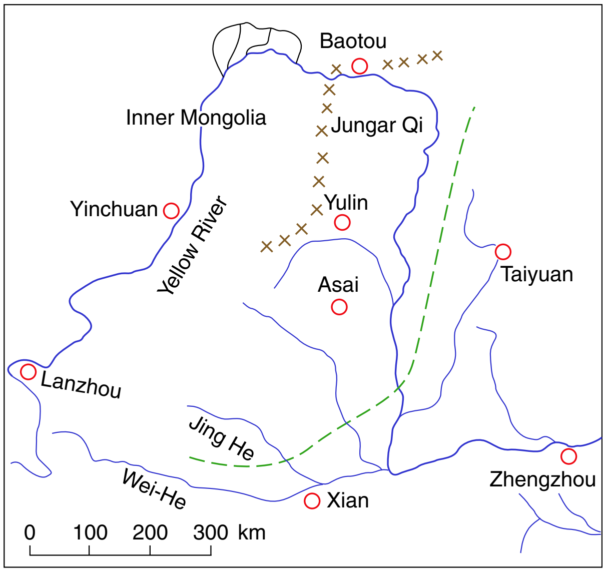


Figure 4 Northwest shift of boundary between dominance of grazing to northwest and farming to southwest between third century BCE (dashes) and first century CE (xxxx). Adapted from Ren, M., Zhu, X., 1994. Anthropogenic influences on changes in the sediment load of the Yellow River, China, during the Holocene. The Holocene 4, 314–320, with permission from SAGE.

production (Xu, 2003). Apparently, climatic stress combined with cultural pressures led to the rapid degradation of forest vegetation that protected the loess hill slopes. The return of more humid conditions after CE 1100 was not accompanied by reductions in sedimentation rates, owing to suppression of forest regeneration resulting from population growth and growing pressures of cultivation as the boundary between agriculture and animal husbandry shifted north. During the Ming and Qing dynasties (*c.* CE 1370–1912), sedimentation rates averaged $\sim$2.60 cm yr^{-1} (Zhang and Xie, 1982).

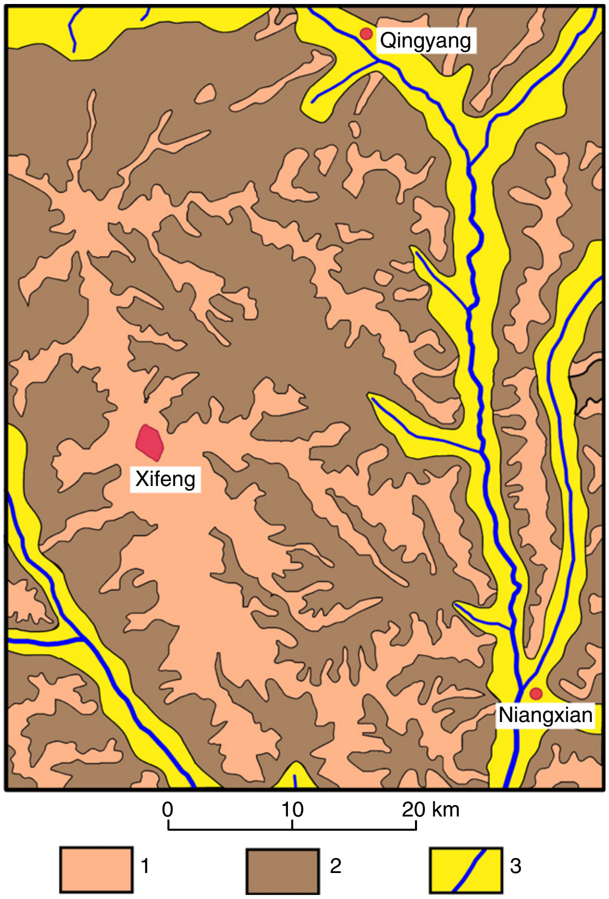


Figure 5 Gully erosion of the Loess Plateau near the Jing River of China. Little of the plateau remains. (1) Remnants of former plateau surface. (2) Plateau surface eroded since Tang Dynasty. (3) Early gullies and valleys. Much of the incision has occurred since the Tang dynasty (618 to 907 CE). Adapted from Ren, M., Zhu, X., 1994. Anthropogenic influences on changes in the sediment load of the Yellow River, China, during the Holocene. The Holocene 4, 314–320, with permission from SAGE.

13.4.2.4 Mesopotamia and Spread of Agriculture to Eastern Mediterranean

Mesopotamia, land between the rivers, was the earliest area where agriculture was established and ultimately progressed to an advanced cultural center. Agricultural developments were initiated in the uplands above the Tigris and Euphrates Rivers, and later a large group of people moved to the lowlands (Braidwood, 1950, 1960). An early model of the advent of agriculture in this region held that farming began suddenly approximately 8000 years BCE after the establishment of earlier sedentary compounds based on hunting and gathering (Mellaart, 1975; Redman, 1978). Later evidence points to earlier agricultural activity dating back to between BCE 10 000 and 8500 and indicating a more gradual domestication of plants and animals and transition to agriculture and sedentary farming in this region (Moore et al., 2000; Akkermans and Schwartz, 2003). The older dates indicate that the Neolithic began to develop in the late Pleistocene, when climates were substantially different and subject to rapid changes (Moore, 1982; Montgomery, 2007). Clearly, the Neolithic expanded and intensified rapidly in the early Holocene as climates warmed. As early as BCE 8000, farm clearings had begun to generate an identifiable record of sedimentation (van Andel et al., 1986; Bintliff, 2002).

Agricultural technology of Mesopotamia reached the eastern Mediterranean by the beginning of the first millennium BCE and was practiced along the Nile River in northern Africa. Technological developments, such as the advent of metal tools and scratch plows, and domestication of large draft animals greatly increased the potential geomorphic effectiveness of early agriculture in Eurasia. The early domestication of oxen in Mesopotamia and the Indus Valley was associated with tilling, and the Greeks are known to have used draft animals and bronze-tipped plowshares, which facilitated land clearance and the breaking of sod. The iron plowshare brought a revolution in agriculture to the Mediterranean. Heavy plows with iron plowshares are first known to have appeared in China approximately BCE 600 (Temple, 1986). The Greeks may have had wheeled plows, although heavier, deep-penetrating wheeled plows probably did not come until later. Removal of

Table 2 Historical stages of sediment production in China

Stage 1 (300 BCE to 550 CE) – Low sedimentation rates ranging from 0.2–0.4 cm yr^{-1}.
Period A–Sedimentation rates increased rapidly between 700 and 1000 CE in response to abrupt environmental change.
Stage 2 (1000–1850 CE) – Sedimentation rates were consistently higher at $\sim$2.0 cm yr^{-1} but without an increase during the period.
Stage 3 (1850–1980 CE) – Sedimentation rates increased rapidly from 2 to 8 cm yr^{-1}.

upland forests and intensification of agriculture in these areas was followed by soil erosion and sedimentation of lowlands. Frequent and thorough plowing in straight lines with closely spaced furrows was considered to be a good land-use practice during the Classic period (Bennett, 1939). Roman agriculture adopted much of the Assyrian and Greek technology from Mesopotamia and the eastern Mediterranean, and introduced it across the areas of Roman dominion. By 200 CE the agricultural traditions and engineering works in the eastern Mediterranean had been largely lost from the region. Today, although the uplands can climatically support forest, trees are missing from many areas of the eastern Mediterranean because the soil is gone (Bennett, 1939). Intensive agricultural practices and technology eventually spread north and west from the Mediterranean (Cunliffe, 2008).

Early stratigraphic studies of Holocene alluvium in the eastern Mediterranean region generated a debate about climate versus human changes. A basic late Quaternary stratigraphy of the Mediterranean was described by Vita-Finzi (1969), who postulated two primary sedimentary groups: an 'Older Fill' dominated by colluvium and slope wash attributed to colder global climatic conditions during the Pleistocene Epoch, and a 'Younger Fill' composed of late Holocene alluvium throughout river valleys. According to this model, little valley aggradation occurred during the early Holocene but accelerated alluviation of the Younger Fill occurred in response to cooler and wetter climates in the mid to late Holocene. More complex and detailed regional alluvial histories ultimately emerged along with substantial evidence of human activity explaining some of the late Holocene alluvium (Younger Fill) in the Mediterranean. In the 1980s, an argument was advanced that human activities had been substantial during the Holocene and that erosive processes of forest clearance and poor land management, followed by land abandonment and slope failures, were related to some of the massive sedimentation events documented by alluvial units in these areas (van Andel et al.,1986; cf. Bintliff, 2002).

13.4.2.5 Neolithic Expansion Across Europe

Mesolithic hunters and gatherers had largely foraged beneath forest canopy, but the Neolithic was associated with intensified forest clearance through the use of stone axes and fire around expanding agricultural settlements (Darby, 1956; Price, 2000). Most domesticated staple crops and large herd animals (wheat, barley, flax, cattle, sheep, goats, and pigs) in early Neolithic Europe came from the Near East sometime after BCE 10 000 and spread across Europe relatively quickly, reaching northwestern Europe by BCE 4000 (Price, 2000). Many agricultural elements appeared in Greece from the Near East approximately BCE 7000, perhaps by colonization (DeMoule and Perlés, 1993) or adoption of practices by indigenous groups (Tringham, 2000). The view that settlements were located primarily on upland sites was initially over-emphasized. Many Greek settlements were established on natural levees of river floodplains and adjacent to lakes where fertile soils, fish, wildlife, and water were abundant (van Andel and Runnels, 1995). Early floodplain settlement sites were later buried by alluvium when farming moved up onto erosive hillslopes.

Most fluvial systems in central Europe were stable from BCE 8000 to 5500, but increasing hillslope erosion and overbank deposition was associated with the onset of the Neolithic *c.* BCE 5500 (Kalis et al., 2003; Lang et al., 2003; Hoffmann et al., 2008). In general, human occupations in Europe were more or less continuous throughout the Holocene (Clark et al., 1989; Dearing, 2006; Kaplan et al., 2009), but population densities, intensity of land use, and geomorphic responses varied greatly through time and space. Over the past 6000 years, some areas in Europe experienced multiple cycles of land clearance, abandonment, and reforestation (Godlowska et al., 1987; Behre, 1988; Bintliff, 1993; Macklin and Lewin, 1993; Gaillard, 2007; Hoffmann et al., 2008). For example, Holocene fluvial changes along the Rhine river catchment in central Europe were strongly influenced by human activities (Lang et al., 2003). In the upper Rhine Basin, settlements began as early as BCE 4000, as is evidenced by the appearance of cereal and other agriculture-related pollen. Pollen evidence indicates that much of northern and central Europe had been covered by thick broadleaf forest up to Roman time. The spread of Neolithic farming was associated with local clearings around settlement sites where the dominant pollen shifted to weeds and grain (Godlowska et al., 1987; Brown, 1997). Geomorphic responses to these clearings were initially confined to local erosion and sedimentation. Substantial fluvial overbank deposition did not begin until later. Lang et al. (2003) describe a general model in which deliveries of anthropogenic sediment do not begin to reach larger floodplains in central Europe until the Iron Age and Roman occupation (cf. Figure 17 *in* Chapter 9.37). Based on a statistical analysis of ^{14}C dates throughout Germany, Hoffmann et al. (2008) conclude that floodplain sedimentation in central Europe began somewhat earlier, by $\sim$ BCE 500 during the Bronze Age. This period coincides with population growth, large-scale land-use change, and slope erosion as well as episodes of climate change.

Early innovations such as the wheel, breeding of draft animals, the harness, and seaworthy cargo ships were important to interregional transport of agricultural products and other resources throughout Europe. The opening of long-distance trade hastened agricultural expansion in northern and western Europe and was associated with accelerated deforestation and deep, extensive plowing. Draft animals facilitated transport of agricultural goods to markets and harbors where surpluses could be traded, thus increasing incentives to clear land for agriculture and raising the potential for episodic upland erosion and lowland sedimentation. Horses had been domesticated by the fifth millennium BCE and began to replace or augment oxen for transporting wheeled vehicles by BCE 3500 (Cunliffe, 2008).

In Britain, records of flooding reconstructed from archives of river alluvium, ^{14}C frequencies, and comparisons between periods of known Holocene climate change and introductions of agricultural and other technologies were summarized by Macklin and Lewin (2008). They concluded that early impacts of agricultural clearance in Britain were primarily changes in catchment hydrology in the form of large floods and local sedimentation in small lakes and wetlands. Sediment deliveries to large rivers were much slower to respond. Humans had no broadly extensive impacts on fluvial systems until after introduction of the scratch plow *c.* 3600 cal. years BP. The beginning of the Iron Age in Britain, *c.* 2650 cal. years BP, marked the beginning of a period of increased fluvial activity. Until Roman occupation, however, anthropogenic impacts in Britain were largely hydrologic. Extensive floodplain sedimentation caused by agriculture did not increase until after *c.* CE 1000 and increased up until *c.* CE 1350 with the Black Death (Macklin and Lewin, 2008)

13.4.2.5.1 Deforestation of Europe

The deforestation of Europe has been studied in some detail. Kaplan et al. (2009) developed a model for deforestation in Europe by fitting a sigmoidal curve to the relationship between a normalized preindustrial forest cover and normalized population density for known chronologies in England, Wales, Greece, France, Ireland, Sweden, and Denmark during periods of forest transition. Forest cover was normalized by considering only land that could be used for crops, pasture, or habitations. Population density was normalized by considering only populations in areas of arable land weighted by a measure of land suitability. The rate of increase in deforestation with population density was greatest for low population densities, that is, during the transition from hunter–gatherer to sedentary agricultural societies. They mapped 'suitable lands' based on soil and climate characteristics and used those maps to compute proportions of the suitable lands that had been deforested.

Deforestation in Europe was simulated for a series of time periods over the past 3000 years (**Figure 6**). These models postulate intense land clearance in the Near East by BCE 1000, the earliest time of the model, owing to high population pressures and small proportions of quality agricultural land. Substantial clearance can also be seen in small areas of central Europe in this early period, although most of the continent was relatively undisturbed at that time. Between BCE 300 BCE CE 350, however, much of southern and western Europe was severely deforested, including Greece, Italy, Spain, France, Germany, Poland, and the southern U.K. Much of northern and eastern Europe remained forested up through CE 350. Between CE 350 and 1000, deforested areas were maintained in southern and western Europe and deforestation began to spread into eastern Europe. Evidence of reforestation can be seen in a few locations such as Greece during this period. Deforestation rates were subdued somewhat after CE 1000 due to population reductions during the Black Death, but by CE 1500 areas of deforestation were extensive throughout Europe. By 1850, the highest rates of forest clearance in the simulations occurred in areas of Eastern Europe (e.g., Romania and Bulgaria) that experienced rapid deforestation for the first time. Most suitable land in Europe had been cleared by the time of industrialization (Kaplan et al., 2009).

13.4.2.6 Pre-European Land Use in the New World

Geomorphic responses to early human alterations to the land in the New World varied greatly through time and space. In general, early erosion and sedimentation in parts of Meso-America and South America were more intense than in mid-latitude regions. Evidence of ecological change caused by early human activities in South and Central America is abundant (Heckenberger et al., 2003; Nevle and Bird, 2008; Dull et al., 2010). Evidence of precontact geomorphic changes has been presented (Butzer, 1992; Beach et al., 2002, 2006; Luzzadder-Beach, and Beach, 2009). For example, Beach et al. (2008) described accelerated erosion in the Maya Lowlands that resulted in deposition of the Maya Clay. Deforestation by Mayans began in Central America approximately 4500 BP and intensified between 3500 and 3300 BP (Pohl et al., 1996). Terracing was introduced as early as CE 250, and many terraces persist today under tropical moist forests (Beach et al., 2002, 2006, 2008). Although Bennett (1926) argued that soil erosion was responsible for failure of the Mayan empire, the effectiveness and persistence of the extensive terrace system suggests that they were often successful in controlling erosion (Beach et al., 2002). Similarly, agriculture in Peru and Ecuador supported large populations and utilized advanced systems of erosion control, including stone terraces on steep slopes and terracing on floodplains. Although these terraces were successful until the time of Spanish conquest, modern farmers have not maintained these systems and severe erosion is now occurring (Troeh et al., 2003). Geomorphic impacts of timbering and agriculture in the pre-contact New World were generally not of the same magnitude as the impacts recorded for Eurasian agriculture (James, 2011).

13.4.2.6.1 Assumptions of pristine landscapes

Fluvial geomorphologists in North America commonly assume that pre-Columbian landscapes were free of substantial anthropogenic erosion and sedimentation. This assumption is commonly made in North American studies of post-contact alluvium, that is, legacy sediment (Walter and Merritts, 2009; Merritts et al., 2011), or stream restorations based on an undisturbed reference reach (Rosgen, 1996). In contrast, the environmental impacts of Native Americans have been vastly revised in recent years. Geoarchaeologists, anthropologists, and cultural geographers have attacked the assumption of relatively unaltered pre-European landscapes as the 'pristine myth' or 'Eden fallacy', citing evidence of large pre-Columbian populations and extensive environmental change (Denevan, 1992; Doolittle, 1992; Butzer, 1996; Redman, 1999; Mann, 2005). It has been shown that sophisticated pre-Columbian cropping and irrigation methods made major environmental changes (Doolittle, 2000; Whitmore and Turner, 2002; Denevan, 2003). Repeated episodes of destructive land

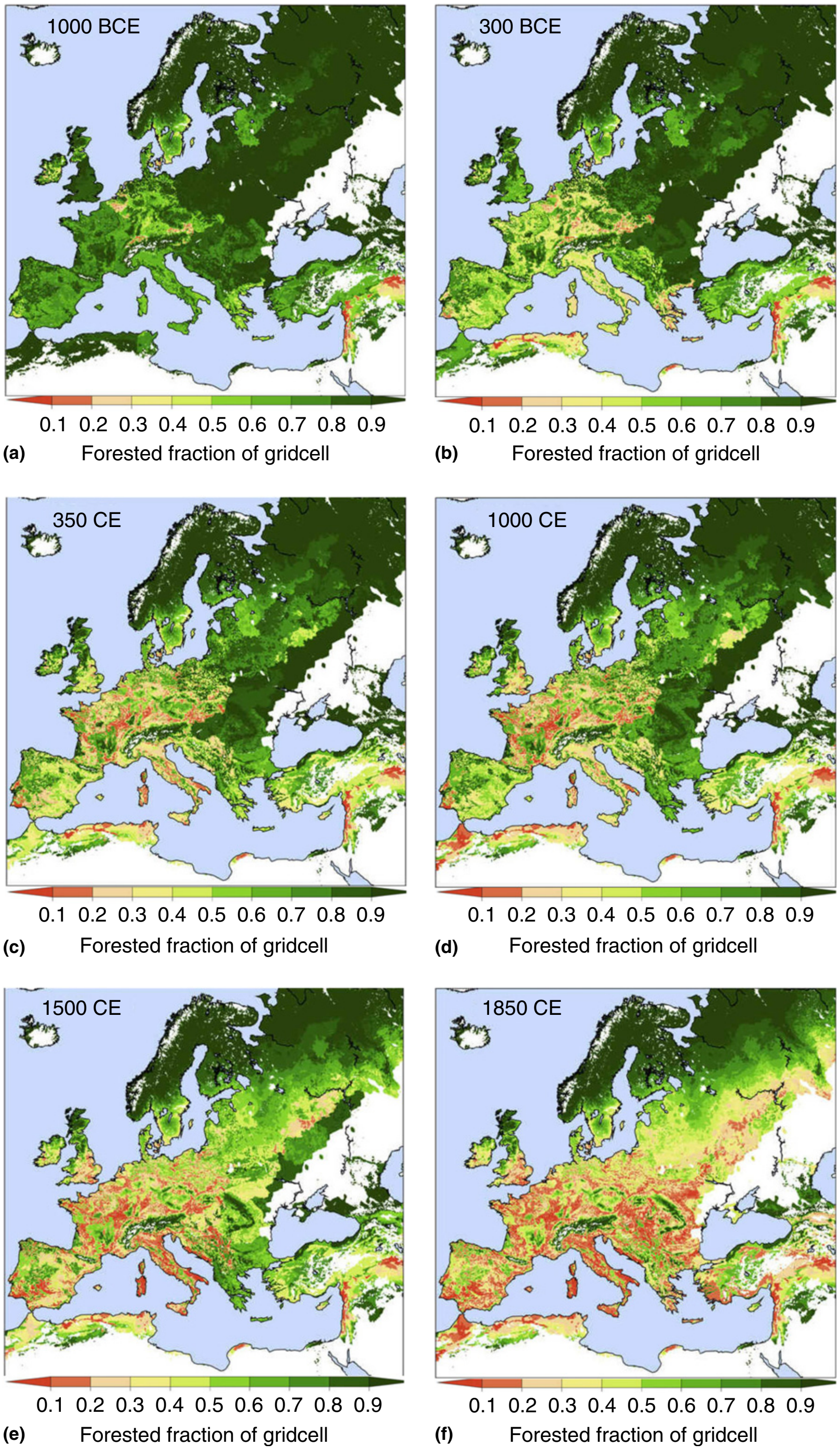


Figure 6 Deforestation of Europe. Six time periods showing systematic expansion of deforested areas with some areas of reforestation in later periods. See text for explanation of methods used to construct the maps. Reproduced from Kaplan, J.O., Krumhardt, K.M., Zimmermann, N., 2009. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews 28, 3016–3034.

management may have resulted in substantial cumulative environmental changes (Redman, 1999).

A first step in any attempt to reconcile this apparent contradiction is to recognize an inherent difference between the ecological alterations commonly cited as the environmental changes in questions of New World anthropogenic impacts, and geomorphic changes generated by erosion and deposition of sediment that may require substantially different land-use changes (James, 2011). Although pre-Columbian agricultural activities in the New World had major impacts on ecological systems (Denevan, 2003; Whitmore and Turner, 2002), geomorphic impacts were often relatively subtle (James, 2011). The geomorphic effectiveness of agriculture in the form of erosion and sedimentation varied greatly, however, through space and time with physiographic, demographic, and cultural factors. A second step, therefore, is to recognize fundamental geographic differences between cultures and regions with respect to the intensity of agriculture employed and its potential for geomorphic change. Geomorphic responses to colonization varied across cultural groups, climates, and physiographic regions. Distinctions are needed between the backgrounds of settlers, their concepts of land stewardship, and physical environments of settlements. Many European cultures had sophisticated land-management systems with conservation strategies. Some settlers brought these systems with them, whereas others learned and adopted the land-use practices of the natives and avoided geomorphic degradation in that way (Butzer, 1996).

The spatial and temporal variability of pre-Columbian agriculture is an important factor in determining the nature of precontact changes in the New World. Before the arrival of Europeans, agriculture was quite extensive in many parts of the Western Hemisphere, especially in the tropics of South America, Central America, and the Caribbean (**Figure 7**). Although some areas of North America had experienced intensive agricultural development, large areas had never experienced a substantial form of agriculture before the arrival of Europeans.

Figure 7 Precontact agricultural lands of the Western Hemisphere. Adapted from Denevan, W.M., 1992. The pristine myth: the landscape of the Americas in 1492. Annals Association of American Geographers 82(3), 369–385, and Nevle, R.J., Bird, D.K., 2008. Effects of syn-pandemic fire reduction and reforestation in the tropical Americas on atmospheric CO_2 during European conquest. Palaeogeography, Palaeoclimatology, Palaeoecology 264(1–2), 25–38.

Several factors inherent to New World technology limited the potential for pre-Columbian land-use intensity. For example, lack of the wheel, large domesticated animals, or large naval vessels limited the capacity of an export economy. New World agriculture did not benefit from animal power for plowing or transportation (Diamond, 1997; Goudie, 2005). Lack of large domesticated animals restricted the ability to clear and plow land, or transport agricultural goods large distances. This, in turn, limited the intensity of agricultural production to crops that could be used within a relatively restricted periphery.

Australia was one of the least altered landscapes before European colonization because the indigenous peoples did not practice agriculture (Diamond, 1997). Before European settlement aboriginal Australians were hunter–gatherer societies. Even in Australia, however, large precolonial disturbances have been noted in New South Wales (Butzer and Helgren, 2005). Moreover, when ecological changes are considered, changes in megafauna, such as the eradication of flightless birds and introduction of feral dogs (dingos), had widespread impacts.

13.4.2.6.2 Pre-Columbian human impacts in North America

Anthropogenic influences had begun in North America by BCE 9000, but, as in Eurasia, the initial environmental impacts were primarily limited to fire and changes in grazing pressures. In eastern North America, the Archaic cultural period ($\sim$10 000 to 2800 BP) was associated with occupation of most forested areas with a small, sparse population of foragers. The introduction of squash and bottle gourd across eastern North America from Mexico suggests early horticultural experimentation between BCE 5000 and 2000 (Delcourt and Delcourt, 1987, 2004). The Woodland cultural period (BCE 800 to CE 1000) was associated with increased populations, intensified agriculture, and clearing of bottomland forests along large rivers. The Mississippian cultural period (CE 1000–1500) saw further increases in population, cultivation of beans and maize, further clearance of riparian forest, and the appearance of city centers (Delcourt and Delcourt, 1987, 2004). By late-Mississipian time, vegetation alteration along some large river valleys was substantial, and wood clearance had moved up slopes near large city settlements in at least one case, Cahokia, along the Mississippi River in southern Illinois. Populations of the Mississippian culture declined suddenly $\sim$CE 1500 for unknown reasons before European contact. Although inferences can be made about erosion and sedimentation associated with late Mississippian forest clearance (Delcourt and Delcourt, 2004), little stratigraphic evidence has been produced to demonstrate that such processes were geographically extensive or locally intensive. In contrast, extensive geomorphic impacts of land clearance and agriculture in Eurasia have been clearly documented.

13.4.3 Intensification of Agriculture in Eurasia

As Eurasian agriculture continued to be practiced, technological developments followed, such as the advent of metal tools for forest clearance, plowing, and harvesting. Expansion of deforestation and agriculture during the periods of late prehistory and early history is described here for Europe. Intensification of agriculture in the upper Rhine Lowlands began in the late Iron Age (BCE 400–1) and continued into the Roman period as is evidenced by decreased woodland pollen and increased cereal, weed, and pasture-grass pollen (Lang et al., 2003). This was a period of expanded forest clearance, population growth, and mining associated with rapid erosion and sedimentation. It came to an end with the retreat of the Romans, after which populations declined, settlements and agricultural fields were abandoned, and watershed responses decelerated. By the middle of the sixth century CE, ~90% of Germany was reforested (Lang et al., 2003). Additional episodes of widespread alluvial sedimentation in Rhine tributaries were initiated during the fifth to seventh centuries CE and during the Medieval climatic optimum (tenth to twelfth centuries CE) in response to mining and colonization. For example, two episodes of severe erosion accompanied by gully incision and followed by healing are documented in western Germany as a synthesis of the timing of agriculture and soil erosion from CE 600 to present (Lang et al., 2003) (**Figure 8**). This sequence shows that rapid forest clearance from CE 600 to 1300 culminated in an episode of severe soil erosion.

Connectivity between hill-slope sediment production and deliveries to channels downstream in Rhine River tributaries increased from the Neolithic through historic periods. The delivery of sediment and responses in downstream river morphology and storage relied on major climatic events to transport sediment downstream (Lang et al., 2003). Not all watersheds responded to the introduction of agriculture in the same way, depending on changing landscape sensitivities and the nature of agriculture employed. Each successive period of sediment production moved the zone of dominant sedimentation further downstream into larger rivers. In the early and late Neolithic periods, agriculturally derived sediment was primarily redistributed on hill slopes and did not reach floodplains. During the Bronze and early Iron Ages, deposition reaching the lower slopes was substantial, and during the pre-Roman Iron Age and the Roman period, gullying began for the first time, older colluvium began to be reworked, and sediment began to reach floodplains. During the fourteenth and eighteenth centuries, degradation and gullying were so severe that farming ceased in some areas. Soil erosion was much greater than modern rates, and most fluvial sediment stored along rivers was derived during this period (Lang et al., 2003). Erosion and sedimentation in very small catchments of central Europe since BCE 5000 are reviewed by Dotterweich (2008). The greatest degree of activity in small catchments of central Europe occurred in the early fourteenth, mid-eighteenth, and early nineteenth centuries CE, when the majority of gully systems were catastrophically initiated.

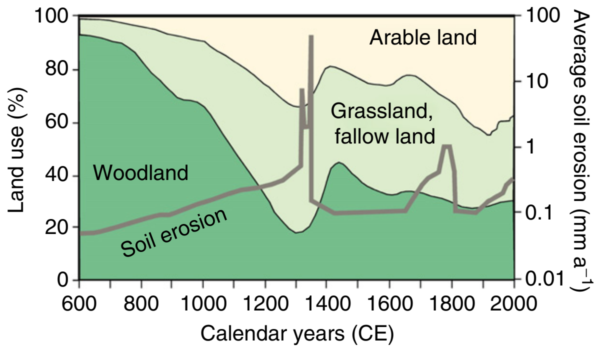


Figure 8 Generalized land-cover changes in Germany (excluding Alps) from CE 600 to present. Rapid, progressive forest clearance from ~CE 700 to 1300 was accompanied by an expansion of arable and grass land until CE 1300. An intense erosion episode (solid line) occurred at the end of the period of maximum clearance. Adapted from Lang, A., Bork, H.-R., Mäckel, R., Preston, N., Wunderlich, J., Dikau, R., 2003. Changes in sediment flux and storage within a fluvial system: some examples from the Rhine catchment. Hydrologic Processes 17, 3321–3334, and Bork, H.R., Bork, H., Dalchow, C., et al., 1998. Landschaftsentwicklung in Mitteleuropa. Wirkungen des Menschen auf Landschaften. Klett-Perthes, Gotha, 328. (in German; cited by Lang et al., 2003).

13.4.3.1 Increasing Potential for Geomorphic Effectiveness

Technological developments increased the potential for land-use change, and economic developments often increased motives to clear land. Heavy, wheeled plows with iron plowshares were introduced in Europe by the beginning of historical records, which enabled farming of the heavier wooded soils (Darby, 1956). For more than two millennia, fleets of war and merchant vessels promoted shipping of vast quantities of goods across the Mediterranean and up the Atlantic coast. The resulting markets promoted intensive land-use practices that characteristically resulted in severe soil erosion. During the Mechanical Age, damming of most streams to exploit water power and a proliferation of grist and saw mills across Europe led to increasing exports of grain and timber.

By the Middle Ages, land clearance and deep plowing could be accomplished relatively quickly and efficiently by contemporary European technology, and forest clearing progressed rapidly. Multiple episodes of forest clearance, erosion, and sedimentation had already been experienced in some basins (Lang et al., 2003; de Moor et al., 2008). By the 1500s, shortages of timber began to be noted and accelerated forest clearance was associated with severe erosion and sedimentation. In some parts of Europe evidence of two or three episodes of erosion and sedimentation represent settlement and forest clearance by different cultural groups followed by long periods of reforestation and landscape healing. In the Geul River of the Netherlands, two periods of severe deforestation, soil erosion, and floodplain alluviation have been documented: one during the Roman Period and another during the High Middle Ages (CE 1000–1500) (de Moor et al., 2008). The timing of the various erosion and sedimentation episodes typically varies from region to region and from watershed to watershed with the serendipity of settlement location and heterogeneity of settlement types. In essence, human activities increased connectivity between hillslopes and river systems (Houben, 2008).

By the time Columbus reached the Americas, agriculture had the potential to be more erosive in Europe than in the New World, owing to agricultural and timbering technologies that facilitated land clearance, deep plowing, and processing and transport of goods. Mechanical technologies had been encouraged by labor shortages induced by the great European pandemic *c.* 1350 (the Black Plague), surplus trade economies that rewarded excess production, and Western concepts of land management that tended to elevate humans above nature and absolve society from a responsibility for stewardship (Marsh, 1864).

By the first half of the seventeenth century, wheeled plows allowed farmers in Britain to plow three times a year for wheat and rye (Fussell, 1935). During the colonial period, disincentives attached to poor land management were often lost as land became relatively abundant. This resulted in the adverse effects of intensive agriculture or timbering combined with poor land management. As agriculture intensified and expanded up slopes, erosion was exacerbated.

13.4.3.2 Explanations for Advanced Eurasian Technology

The classic explanation for the spread of agriculture into Europe from the Middle East is by cultural contact (Childe, 1925; Tringham, 2000). Theories of a simple migratory spread of farming populations across Europe during the Neolithic, however, have been discounted (Richards, 2003). Independent development of farming by indigenous groups (Dennell, 1992) is difficult to reconcile with evidence of Neolithic settlements where no Mesolithic cultures existed previously and does not explain strong spatio-temporal patterns of progressively younger Neolithic sites to the north and west of the Aegean or the spread of artifacts (van Andel and Runnels, 1995). The classic wave-of-advance theory holds that the spread of agriculture during the Neolithic advanced outward from cultural hearths such as Mesopotamia. A revised wave-of-advance theory of the spread of cultural development, predicated largely on the lack of geographic barriers, was presented by van Andel and Runnels, (1995) and advanced by Diamond (1997).

According to the Diamond thesis, high geographic connectivity between Eurasian regions (Europe, Asia, and North Africa) fostered the rapid and repeated spread of ideas, materials, and technologies. This resulted in rapid advances in technology and material culture through dispersion, migration, trade, and conquest. As a consequence, Eurasian technologies – including agriculture – had advanced well beyond civilizations in other continents, for example, the Americas, Australia, and sub-Saharan Africa. Other regions were isolated by oceans, mountains, deserts, tropical rainforests, or other geographic barriers that arrested the spread of technology and domesticated plants and animals (Diamond, 1997). Regions dominated by geographic barriers did not experience the level of complexity or diversity of agricultural development that was experienced in Eurasia. For example, the Isthmus of Panama posed a formidable barrier between North and South America so that the spread of ideas, technologies, and cultivars was severely hampered. An important aspect of this theory is that cultural developments prevail over race; that is, differences between racial groups were relatively minor, but technology and knowledge exchanges established critical differences between groups.

The geographical spread of prehistoric agriculture from Asia to the West (Hobson, 2004) and from the Mediterranean to northern Europe (Cunliffe, 2008) demonstrate the high connectivity in Eurasia throughout prehistory and historical time. A large number of conquests and migrations across Europe and the Middle East emanated from Asia and southern Europe in prehistory. Neolithic migrations were quick because agricultural settlers easily displaced hunter–gatherer groups. Expansion continued into the Bronze and Iron Ages and repeatedly exploited land, river, and sea routes that facilitated trade, migration, and invasion. For example, the Danube River provided a corridor from the Aegean Sea into southeastern Europe through which early Neolithic agriculture spread approximately 1500 km between BCE 5500 and 5000, that is, 3 km yr^{-1} or 60 km per generation for 25 generations (**Figure 9**). Once established in central Europe, agriculture

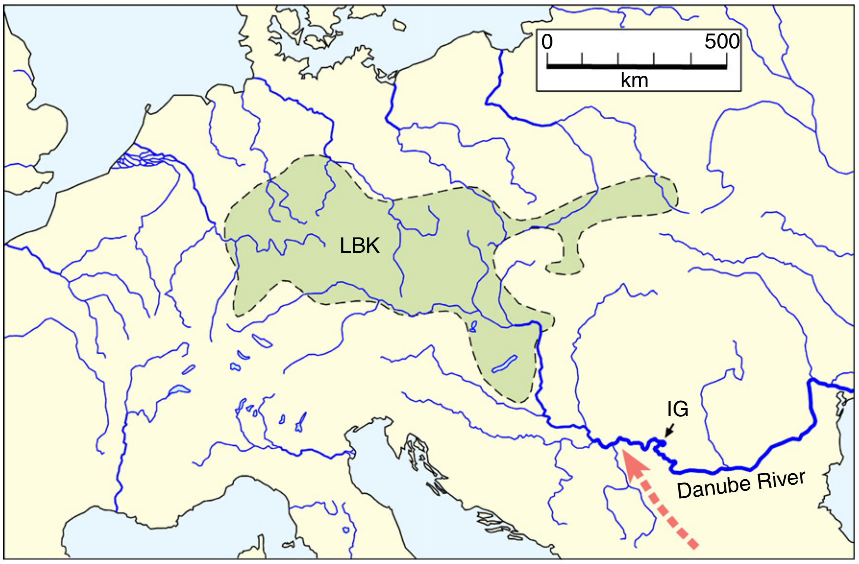


Figure 9 Spread of early Neolithic Linearbandkeramik culture (LBK) up Danube River into central Europe. Arrow in southeast indicates likely routes from Greek Aegean region to Danube River above the Iron Gate gorge (IG). Adapted from Figure 4.11 in Cunliffe, B., 2008. Europe Between the Oceans. Themes and Variation: 9000 BC–AD 1000. Yale University Press, New Haven and London, 518 pp.

could spread along the many river corridors flowing north and west from there.

Long-held debates over the spread of agriculture by migration versus diffusion can be set aside, because archaeological evidence indicates a combination of the two (Gronenborn, 1999; Bentley et al., 2002) and probably mixtures of other processes such as leap-frogging and conquest. Seven possible mechanisms for Neolithic expansion are tested by Richards (2003) using mitochondrial DNA analyses. The results suggest that the genetic component of modern Europeans carries only 12 to 23% of sources from the Near East. This indicates that colonization by settlers from the Near East did occur, which rules out models based solely on cultural diffusion or acculturation, but it also indicates that more than three quarters of the genetic lineage are accounted for by earlier, late Glacial expansions of Paleolithic immigrations from Southwestern Europe (Richards, 2003). Thus, the DNA evidence corroborates the importance of local adoption of agriculture by indigenous groups during the Neolithic transition. Since mitochondrial DNA represent genes passed down by women, however, the possibility remains that the male component of genetic transfer from the Near East was greater than 12 to 23%. In fact, Y chromosome evidence that represents the male component of genetic inheritance indicates a greater contribution from the Near East to Europe, especially along coastlines (Richards, 2003). This evidence suggests that a component of male-dominated colonization, trade, and conquest that adopted wives from the local population may have been important to the transfer of agricultural technology.

13.4.4 Introduction of European Agriculture to the New World

The intensive land clearance associated with European agriculture was potentially highly disruptive to geomorphic systems through massive redistributions of sediment from hill slopes to floodplains. Although the potential was great and, in many cases, the result was episodic, catastrophic geomorphic change did not always occur. A distinction should be made between potential and actual geomorphic effectiveness. The potential to generate erosion and sedimentation varied with physiography and between various cultural groups in the Old and New Worlds at the time of European contact.

13.4.4.1 Colonial Impacts in North America

European colonists arriving in North America introduced Old World agricultural technology and practiced intensive forest clearing (*see* Chapter 13.2). Intensive agriculture rapidly spread westward across North America as frontier settlers cleared land, worked it for a generation or two, and moved west to clear new land. Severe erosion, including sheet erosion and gullying, commonly left the land incapable of sustaining agriculture. With the exception of the use of fire to clear land, pre-Columbian agricultural practices in North America had been relatively benign with regards to generating soil erosion (James, 2011). The introduction of Old World agricultural techniques often resulted in episodic sedimentation across parts of North America that remains in the stratigraphic record as extensive legacy colluvium along valley margins and alluvium on floodplains.

The Piedmont of the southeastern U.S. provides an example of a region that was severely altered by the arrival of European colonists. Settlers began to arrive in the lower Piedmont between 1740 and 1770 (Hall, 1940). They initially farmed along the river lowlands, but as sedimentation began, the bottoms became marshy and agriculture moved up onto steeper slopes that were much more erodible. This, in turn, resulted in accelerated erosion and sedimentation (Trimble, 1974). Charles Lyell visited the Georgia Piedmont in the mid-nineteenth century and described contemporary changes in water quality from black-water streams (rich in carbon) to sediment-laden turbid waters:

> Formerly, even during floods, the Altamaha was transparent, or only stained of a darker color by decayed vegetable matter, like some streams in Europe which flow out of peat mosses. So late as 1841, a resident here could distinguish on which of the two branches of the Altamaha, the Oconee or Ocmulgee, a freshet had occurred, for the lands in the upper country, drained by one of these (the Oconee) had already been partially cleared and cultivated, so that that tributary sent down a copious supply of red mud, while the other (the Ocmulgee) remained clear, though swollen. But no sooner had the Indians been driven out, and the woods of their old hunting grounds begun to give way before the ax of the new settler, than the Ocmulgee also became turbid.
>
> (Charles Lyell, 1849)

When cotton production intensified in the upper Piedmont following the Civil war, erosion rates escalated. By the 1940s, the pre-agricultural soils on floodplains of upper Piedmont rivers were buried by historical alluvium and channel beds were filled with sand (Happ, 1945). The modern sediment volume was approximately one third of the floodplain deposits and was characterized by channel deposits twice as thick as overbank deposits. Happ described the surface layer of historical sediment as a reddish-brown surface layer derived from gully erosion overlying an older soil:

> Practically all the Piedmont valley flood plains are covered with 'modern' sediment, which is defined as the sediment deposited under the influence of accelerated soil erosion since white settlement. The upper two or three feet of alluvium is usually brown or reddish-brown, similar in color to the subsoils of adjacent gullied uplands, and these reddish-brown deposits are generally recognized as the products of accelerated soil erosion.... When traced down the valleys, the buried old topsoil is found at progressively greater depths beneath the flood-plain surface, and within a few miles it usually passes beneath the ground-water table.
>
> (Happ, 1945)

Lack of land conservation measures, combined with a mercantile export economy often resulted in widespread erosion and sedimentation. Furthermore, colonial land-use practices were carried west with the frontier. Frontier settlers cleared land, worked it for a few generations, and then moved farther west to clear new lands. With vast tracts of available land to the west, land was cheap, so severe erosion often ran unchecked, leading to thick alluvial deposits overlying prehistoric floodplain soils (Happ, 1945; James, 2006).

Stratigraphic reconstructions in many temperate North American watersheds indicate low prehistoric sedimentation rates that accelerated greatly following Anglo-American settlement. For example, stable floodplain soils commonly underlie an abrupt historical contact that marks the onset rapid of postsettlement sedimentation rates in the midwestern USA (Knox 1972, 1977, 1987, 2006).

13.4.4.2 Colonial Impacts in Australasia

As in North America, European settlement of Australia was accompanied by the rapid introduction of relatively advanced agricultural technology. Severe land-use changes following the introduction of sheep to the Jerrabomberra Creek watershed, a 136 km^2 catchment in the Tablelands of the upper Murrumbidgee River in southeastern Australia, was associated with channel incision by 1900, which dominated sediment budgets in the lower basin (Wasson et al., 1998). The $\sim$95% of postsettlement sediment derived from channel incision and bank erosion is in contrast with most studies in the region that find sheet, rill, and gully erosion dominate the generation of alluvial sediment. Gully erosion has been a major source of postsettlement alluvium in smaller watersheds of Australia. For example, in a small watershed northeast of Canberra, monitoring of sediment deliveries from hill slopes and analysis of radionuclide tracers indicated that the dominant source of sediment was from erosion of gully headwalls and sidewalls (Olley et al., 1993).

In the Upper Murrumbidgee River, where European settlement began in the 1820s, the primary cause of accelerated erosion was overgrazing (Olley and Wasson, 2003). Severe gullying increased sediment production in headwater catchments by a factor of $\sim$150 compared to a twofold increase in sediment production, which could have been induced by precipitation variability alone. In the first 40 to 50 years of settlement, sediment yields increased by an estimated factor of 200 from $\sim$2400 t yr^{-1} in the presettlement period to $\sim$480 000 t yr^{-1}, primarily due to gullying (Olley and Wasson, 2003). Subsequently, gullies reached their maximum extent and modern sediment yields from small catchments declined to approximately six times pre-settlement yields. Before colonization, sediment yields increased downstream at a 0.79 power of drainage area ($SY = 1.6\,A^{0.79}$). After the period of settlement, this rate had increased to the 0.91 power of drainage area ($SY = 38\,A^{0.91}$) for the period 1945 to 1994. Downstream in larger basins, sediment yields remain approximately 100 times presettlement values ($\sim$240 000 t yr^{-1}) owing to improved conveyance of sediment through the higher drainage density channel system (Olley and Wasson, 2003), and presumably also to reworking of stored alluvium. More examples of post-colonial changes in Australia and New Zealand are reviewed by Harden (*see* Chapter 13.2).

13.4.4.3 Assumptions of Ubiquitous Geomorphic Impacts by Colonization

The dramatic nature of some environmental responses to colonization of the New World may lead to the erroneous conclusion that European settlement was always associated with extreme environmental consequences. This assumption of ubiquity has been critiqued as the 'myth of devastated colonial landscapes' by Butzer (1992, 1996) who provides examples of important exceptions. In stable settlements, cultural mores concerning land management tend to evolve in parallel with the capability to alter landscapes. Cultural beliefs, restrictions, and land-use practices can effectively moderate environmental impacts. For example, Butzer (1996) noted that long-term ecological risk minimization has characterized agrosystem management in some Mediterranean cultures, such as Spanish land-management systems that have maintained conservative and ecologically adaptive strategies for 200 generations. Where these management practices were applied to Spanish livestock grazing in central Mexico, degradation was negligible, and rapid soil erosion did not begin until the 18th century when population pressures rose. Further, Butzer (2000) pointed out that population growth does not necessarily accelerate environmental damage, and that episodes of disequilibrium became less common in later prehistory, suggesting that regional societies learned from conservationist experience. He assigns the maximum rates of erosion to periods of depopulation and rural land abandonment.

Severe damage may have resulted where agricultural practices were based on experience from a different environment (Butzer, 1996). If cultural systems are not suited to the new environment or are not maintained, safeguards may be missing that are essential to maintaining sustainable agriculture. Environmental instabilities may result from improper land-management practices that are geomorphically disruptive. Thus, the impacts of introducing agricultural technology to a new region may vary greatly. Interpretations should distinguish between types of settlement, the land-management practices and mores inherent to the settlers, suitability of those practices to the region settled, and whether the cultural land-management practices are maintained over the long term after settlement.

These factors suggest a potential distinction between Spanish settlements in tropical or subtropical Meso-America and Anglo-American settlements in temperate North America. In general, Spanish settlers maintained long-held land-use management practices, emphasized grazing, acculturated native groups, adopted local crops and land-use practices, and came from subtropical climates. In contrast, many Anglo-American settlers were not farmers, did not bring a culture of land stewardship, did not assimilate local natives, adopted few indigenous land-use practices, and came from northern climates with glaciated landscapes. Anglo Europeans lacked experience with the intense subtropical storms that they encountered in the southeastern United States and – even if they did import European land-management practices, these would have been poorly adapted to the intense, erosive rain storms that are common there.

13.4.4.4 Loss of Environmental Restraints

During the period of colonialist expansion, advanced agricultural and transport technologies were sometimes divorced from cultural controls on land management, and combined with strong economic motivations for resources extraction overseas. Motives of colonists were often different than those of European agriculturalists who had maintained stable settlements or agricultural systems for many generations. Some colonists were motivated by the potential to generate a profit by mining the land and timber resources and selling surplus goods overseas (Brierley et al., 2005). This was facilitated by water-powered saw mills and improved transport of freight by land and sea. Technological innovations coupled with large-scale export economies encouraged geomorphically effective exploitation. Even Anglo-American colonists who maintained permanent residency in the New World, often did not understand land management or regarded land as expendable, knowing that extensive tracts of land were available beyond the frontier. In any case, the ability or motives to practice land stewardship was often diminished or undermined. As a result, accelerated land clearance for agriculture and resource extraction often ensued. Settlers had the technology to rapidly clear land, had economic incentives to do so, and had the potential to generate severe erosion and sedimentation.

13.4.5 Modern Agricultural and Deforestation Impacts

In many regions of the world, land-use intensification came relatively late in the historical period due to climatic or physiographic conditions that are marginal for agriculture. For example, increased erosion and suspended sediment loadings in the early twentieth century have been noted in the Selenga River watershed, the largest tributary to Lake Baikal, and were followed by reductions in the last third of the century (Kortyny et al., 2003). Increased erosion during a period lacking evidence of regional climatic change is attributed to gold-mining, construction of the Trans-Siberian railroad, and population growth that led to expansion of agricultural lands, increases in the number of cattle, and changes in land management.

In the second half of the twentieth century, a major transformation of agriculture took place that is generally referred to as the Green Revolution. This transformation was characterized by reliance on chemical fertilizers and pesticides and abandonment of traditional sustainable practices that replenish soil fertility and utilize fallow periods on land. This movement had great successes and failures (Tilman, 1998). Successes include meeting most of the global food demand in spite of rapid increases in population. Failures include increases in water pollution, generation of greenhouse gases, loss of biodiversity, and accelerated soil erosion and sedimentation. In general, food production outpaced population growth. From 1961 to 2007, global food production increased 138% from 1.84 to 4.38 billion tonnes, whereas global populations grew 123% from 3.0 to 6.7 billion (The Royal Society, 2009). The Green Revolution was accompanied by a geographic spread and intensification of high-yield cultivation, commonly into areas that had not previously been extensively cultivated. The growth can be attributed to a number of factors, including demographic growth in response to improved medical care and sanitation, and technological innovations, such as the introduction of mechanized farm equipment, synthetic fertilizers and pesticides, availability of fossil fuels for pumping irrigation water, and development of high-yield cultivars. The sustainability of intensified agriculture has been questioned on the basis of erosion, loss of soil nutrients, chemical and energy requirements, and crop diseases (Pimentel et al., 1995). Projections for the year 2050 include population growth from 6.9×10^9 in 2010 to 9.3×10^9 (United Nations, 2010) and an increase of between 50 to 100% in food production needed to feed that population (The Royal Society, 2009). Such increases cannot be sustainable, however, because they depend on the expansion of farm land (Pretty, 2008). In fact, expanded land clearance is likely, which will have many implications including geomorphic responses to erosion and sedimentation.

13.4.5.1 Forest Transition and Reforestation

The shift from deforestation to reforestation, referred to as 'forest transition', represents a shift from net deforestation to net reforestation, which is essentially a transition from non-sustainable to sustainable forest management (Mather et al., 1999). Forest transitions were experienced in many locations in Europe and North America, and may be anticipated in developing nations that are now experiencing net deforestation. Forest transitions do not require a decrease in population, but can follow agricultural innovations that increase production from smaller agricultural areas. The inverse relationship between population and forest area has weakened if not reversed in recent decades over a global scale (Mather and Needle, 2000). Forests tend to stabilize before population does, which raises questions about the direction of causality or the primacy of population as a driver of forest clearance. In postindustrial societies, forest transitions have often been accompanied by population shifts to urban areas and a shift from preindustrial to industrial use of forest products. In any case, land no longer needed for agriculture is reforested.

Forest transitions have commonly been associated with crises, such as wood shortages leading to overexploitation of resources or catastrophic periods of flooding and sedimentation associated with deforestation. At least two forest transitions have been identified in France: a Medieval transition (thirteenth and fourteenth centuries) and a modern transition beginning approximately 1800. The first transition had neo-Malthusian characteristics following the Black Plague, whereas the second transition was characterized by an effect in which high population densities resulted in innovations that raised carrying capacities of the land (Mather et al., 1999).

Current efforts to enhance carbon sequestration by reforestation should consider the changes to hydrologic systems. Reforestation does not necessarily generate a return to predisturbance conditions of water and sediment loadings, but substantial decreases in runoff are likely (Bosch and Hewlett, 1982; Jackson et al., 2005; Trabucco et al., 2008). Impacts of forest transition on erosion and sedimentation need more study.

13.4.6 Conclusion

The advent of agriculture during the Neolithic and the deforestation that accompanied it initiated a pervasive human-induced change to the Earth's surface that ultimately had substantial geomorphic impacts. Onset of the Neolithic was time transgressive, beginning more than ten millennia BP in some places but not until much later in others. In some cases, agriculture and land clearance were introduced gradually, but in historical time these changes were commonly imposed suddenly. Locally and regionally, land-use changes usually influence geomorphic systems through increased rates of erosion and sedimentation. This synthesis focused on local and regional land-use changes and the highly variable responses that they had over the late Holocene through historic periods.

The geographic spread of agriculture from the Middle East to the Mediterranean and to Europe occurred by a variety of processes and was accompanied by technological innovations that made humans increasingly effective at clearing land, timbering, and plowing soils. European agriculture, land-use, and transportation technologies, such as heavy plows, saw mills, and sailing vessels, greatly enabled and motivated settlers to clear land. Agriculture and land clearance were not simply introduced to a pristine landscape, but on a humanized landscape of variable geomorphic sensitivity. Pre-Columbian New World agriculture had substantial effects on ecosystems in the regions where it was practiced, but the geomorphic responses were less extensive and often subtle in magnitude relative to the potential responses to European agriculture. Meso-America is a notable exception where substantial anthropogeomorphic change has been noted.

Geomorphic impacts resulting from the introduction of European agriculture to the New World characteristically generated episodic geomorphic responses, although this did not always occur. Geomorphic impacts varied in time and space with: (1) the type of settlement; (2) whether or not cultural values concerning land management accompanied settlement and were maintained; and (3) the physiographic nature of the area being settled. When colonization was decoupled from land-stewardship mores, land-clearance and transportation technologies combined with economic incentives resulted in a potential for extremely erosive practices. Given the high spatial and temporal variability of known geomorphic episodes, simple *a priori* assumptions about pre- and post-Columbian anthropogeomorphic impacts should be avoided. Interpretations of each individual watershed and river basin should be based on a critical evaluation of empirical data from stratigraphic, geoarchaeological, and historical records of land use, erosion, and sedimentation.

References

Akkermans, P.M.M.G., Schwartz, G.M., 2003. The Archaeology of Syria. From Complex Hunter-Gatherers to Early Urban Societies (ca. 16,000-300 BC). Cambridge University Press, Cambridge.

Beach, T., Dunning, N., Luzzadder-Beach, S., Cook, D.E., Lohse, J., 2006. Impacts of the ancient Maya on soils and soil erosion in the central Maya lowlands. Catena 65, 166–178.

Beach, T., Luzzadder-Beach, S., Dunning, N., Cook, D., 2008. Human and natural impacts on fluvial and karst depressions of the Maya Lowlands. Geomorphology 101, 308–331.

Beach, T., Luzzadder-Beach, S., Dunning, N., Hageman, J., Lohse, J., 2002. Upland agriculture in the Maya Lowlands: ancient Maya soil conservation in northwestern Belize. The Geographical Review 92, 372–397.

Behre, K.-E., 1988. The role of man in European vegetation history. In: Huntley, B., Webb, T. (Eds.), Vegetation History. Kluwer, Dordrecht, pp. 633–672.

Bennett, H.H., 1926. Agriculture in Central America. Annals Assn. Amer. Geographers 16, 63–84.

Bennett, H.H., 1939. Soil Conservation. McGraw-Hill Book Co., New York, 993 pp.

Bentley, R.A., Price, T .D., Lüning, J., Gronenborn, D., Wahl, J., Fullagar, P.D., 2002. Prehistoric migration in Europe: Strontium isotope analysis of early Neolithic skeletons. Current Anthropology 43, 799–804.

Bintliff, J.L., 1993. Forest cover, agricultural intensity and population density in Roman imperial Boeotia, central Greece. In: Frenzel, B. (Ed.), Evaluation of Land Surfaces Cleared from Forests in the Mediterranean Region During the Time of the Roman Empire. Fischer Verlag, Stuttgart, pp. 133–143.

Bintliff, J., 2002. Time, process and catastrophism in the study of Mediterranean alluvial history: a review. World Archaeology 33(3), 417–435.

Bork, H.R., Bork, H., Dalchow, C., et al., 1998. Landschaftsentwicklung in Mitteleuropa. Wirkungen des Menschen auf Landschaften. Klett-Perthes, Gotha, 328. (in German; cited by Lang et al., 2003).

Bosch, J.M., Hewlett, J.D., 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55(1–4), 3–23.

Braidwood, R.J., 1950. Jarmo: a village of early farmers in Iraq. Antiquity 24, 189–195.

Braidwood, R.J., 1960. The agricultural revolution. Scientific American 203(3), 130–148.

Brierley, G.J., Brooks, A.P., Fryirs, K.A., Taylor, M.A., 2005. Did humid-temperate rivers in the old and new worlds respond differently to clearance of riparian vegetation and removal of woody debris? Progress in Physical Geography 29, 27–49.

Brown, A.G., 1997. Alluvial Geoarchaeology: Floodplain Archaeology and Environmental Change. Cambridge University Press, Cambridge, UK, 377 pp.

Butzer, K.W., 1982. Archaeology as Human Ecology. Cambridge University Press, Cambridge, UK.

Butzer, K.W., 1992. The Americas before and after 1492: an introduction to current geographical research. Annals Association of American Geographers 82(3), 345–368.

Butzer, K.W., 1996. Ecology in the long view: settlement histories, agrosystemic strategies, and ecological performance. Journ. Field Archaeology 23(2), 141–150.

Butzer, K. W. 2000. Human impact on ancient environments. Science. 287.5462: 2427

Butzer, K.W., Helgren, D.M., 2005. Livestock, land cover, and environmental history: the tablelands of New South Wales, Australia, 1820–1920. Annals Association of American Geographers 95(1), 80–111.

Cassals, R., 1984. The role of prehistoric man in the faunal extinctions of New Zealand and other Pacific islands. In: Martin, P.S., Klein, R.G. (Eds.), Quaternary Extinctions: A Prehistoric Revolution. University of Arizona Press, Tucson, AZ.

Childe, V.G., 1925. The Dawn of European Civilisation. Kean Paul, London.

Clark, P.J., Merkt, J., Müller, H., H., 1989. Post-glacial fire, vegetation, and human history on the Northern alpine forelands, South-Western Germany. Journal of Ecology 77, 897–925.

Cunliffe, B., 2008. Europe Between the Oceans. Themes and Variation: 9000 BC-AD 1000. Yale University Press, New Haven and London, 518 pp.

Dakang, Z., Peiyuan, Z., 1990. The Huang-Huai-Hai plain. In: Turner, II B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (Eds.), The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge, UK, Chapter 28, pp. 473–477.

Darby, H.C. 1956. The clearing of the woodland in Europe, In, Thomas, W.L. Jr. Sauer, C.O. Bates, M. Mumford L. (Eds.), Man's Role in Changing the Face of the Earth, University of Chicago Press, Chicago, vol. 1, pp. 183–216, 448.

Dearing, J.A., 2006. Climate-human-environment interactions: resolving our past. Climate Past 2, 187–203.

Degens, E.T., Ross, D.A., 1974. The Black Sea: Geology, Chemistry and Biology, Memoir 20. American Association of Petroleum Geologists, Tulsa, Okla. 633 pp.

Degens, E.T., Stoffers, P., Golubic, S., Dickman, M.D., 1978. Varve chronology: estimated rates of sedimentation in the Black Sea deep basin. In: Ross, D.A., Neprochnov, Y.P., Hsü, K.J., et al. (Eds.), Initial Reports of the Deep Sea Drilling Project 42, part 2. U.S. Govt. Printing Office, Washington, DC, pp. 499–508.

Delcourt, P.A., Delcourt, H.R., 1987. Long-Term Forest Dynamics of the Temperate Zone: A Case Study of Late-Quaternary Forests in Eastern North America. Springer-Verlag, N.Y., 439 pp.

Delcourt, P.A., Delcourt, H.R., 2004. Prehistoric Native Americans and Ecological Change. Cambridge University Press, 203 pp.

de Moor, J.J.W., Kasse, C., van Balen, R., Vandenberghe, J., Wallinga, J., 2008. Human and climate impact on catchment development during the Holocene: the Geul River, the Netherlands. Geomorphology 98, 316–339.
DeMoule, J.–P., Perlés, C., 1993. The Greek Neolithic: a new review. Journal of World Prehistory 7, 355–416.
Denevan, W.M., 1992. The pristine myth: the landscape of the Americas in 1492. Annals Association of American Geographers 82(3), 369–385.
Denevan, W.M., 2003. Cultivated Landscapes of Native Amazonia and the Andes. Oxford University Press, New York, 396 pp.
Dennell, R.W., 1992. The origins of crop agriculture in Europe. In: Cowan, C.W., Watson, P.J. (Eds.), The Origins of Agriculture. Wash. Smithsonian Institute Press, DC, pp. 71–100.
Diamond, J., 1997. Guns. Germs, and Steel: The Fates of Human Societies. W.W. Norton & Company, New York, NY.
Doolittle, W.E., 1992. Agriculture in North America on the eve of contact: a reassessment. Annals Association of American Geographers 82(3), 386–401.
Doolittle, W.E., 2000. Cultivated Landscapes of Native North America. Oxford University Press, New York.
Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: deciphering the long-term interaction between humans and the environment – a review. Geomorphology 101, 192–208.
Dull, R.A., Nevle, R.J., Woods, W.I., Bird, D.K., Avnery, S., Denevan, W.M., 2010. The Columbian encounter and the Little Ice Age: abrupt land use change, fire, and greenhouse forcing. Annals Association of American Geographers 4, 755–771. http://dx.doi.org/10.1080/00045608.2010.502432.
Elvin, M., 2004. The Retreat of the Elephants: An Environmental History of China. Yale University Press, New Haven and London, 564 pp.
Flannery, K.V., 1969. Effects of early domestication in Iran and the Near East. In: Ucko, P.J., Dimbleby, G.W. (Eds.), The Domestication and Exploitation of Plants and Animals. Aldine Press, Chicago, pp. 73–100.
Fussell, G.E., 1935. Farming methods in the Early Stuart Period. I. The Journal of Modern History 7(1), 1–21.
Gaillard, M.-J., 2007. Detecting human impact in the pollen record. In: Elias, S.A. (Ed.), Encyclopedia of Quaternary Science. Elsevier Ltd., London, pp. 2570–2595, ISBN: 978-0-444-52747-9.
Godlowska, M, Kozlowski, J., Starkel, L., Wasylikowa, K., 1987. Neolithic settlement at Pleszow and changes in the natural environment in the Vistula Valley. Przeglad Archeologiczny 34, 133–159.
Goudie, A., 2005. The Human Impact on the Natural Environment: Past Present, Future, Sixth ed. Blackwell, Oxford, UK.
Gronenborn, D., 1999. A variation on a basic theme: the transition to farming in southern Central Europe. Journal of World Prehistory 13, 123–210.
Hall, A.R., 1940. The Story of Soil Conservation in the South Carolina Piedmont, 1800–1860. U.S. Department of Agriculture, Misc. Pub. 407, U.S. Govt. Printing Office, Washington, DC.
Happ, S., 1945. Sedimentation in South Carolina Piedmont valleys. American Journal of Science 243, 113–126.
Hay, W.W., 1994. Pleistocene-Holocene fluxes are not the Earth's norm. In: Hay, W.W., Andrews, J.T., Baker, V.R., et al. (Eds.), Panel on Global Surficial Geofluxes, Material Fluxes on the Surface of the Earth. National Academy Press, Washington, DC, pp. 15–27.
Heckenberger, M.J., Kuikuro, A., Kuikoro, U.T., Russell, J.C., Schmidt, M., Fausto, C., Franchetto, B., 2003. Amazonia 1492: pristine forest or cultural parkland? Science 301, 1710–1714.
Hobson, J. M. 2004. The Eastern Origins of Western Civilisation, University of Cambridge Press Cambridge, UK.
Hoffmann, T., Erkens, G., Gerlach, R., Klostermann, J., Lang, A., 2009. Trends and controls of Holocene floodplain sedimentation in the Rhine catchment. Catena 77, 96–106.
Hoffmann, T., Lang, A., Dikau, R., 2008. Holocene river activity: analysing 14C-dated fluvial and colluvial sediments from Germany. Quaternary Science Reviews 27, 2031–2040.
Houben, P., 2008. Scale linkage and contingency effects of field-scale and hillslope-scale controls of long-term soil erosion: anthropogeomorphic sediment flux in agricultural loess watersheds of Southern Germany. Geomorphology 101, 172–191.
Houben, P., Hoffmann, T., Zimmermann, A., Dikau, R., 2006. Land use and climatic impacts on the Rhine system (RheinLUCIFS): quantifying sediment fluxes and human impact with available data. Catena 66, 42–52.
Jackson, R.B., Jobbágy, E.G., Avissar, R., et al., 2005. Trading water for carbon with biological carbon sequestration. Science 310(5756), 1944–1947.
James, L.A., 2006. Bed waves at the basin scale: implications for river management and restoration. Earth Surface Processes and Landforms 31, 1692–1706.
James, L.A., 2010. Secular sediment waves, channel bed waves, and legacy sediment. Geography Compass 2/6, 1–23. http://dx.doi.org/10:1111/j.1749-8198.2010.00324.x.
James, L.A., 2011. Contrasting geomorphic impacts of pre- and post-Columbian land-use changes in Anglo America. Physical Geography 32(5), 399–422. http://dx.doi.org/10.2747/0272-3646.32.5.399.
Jones, A., 2008. Introduction. In: Jones, A. (Ed.), Prehistoric Europe: Theory and Practice. Wiley-Blackwell, Chichester, UK, pp. 1–15.
Kalis, A.J., Merkt, J., Wunderlich, J., 2003. Environmental changes during the Holocene climatic optimum in central Europe – human impact and natural causes. Quaternary Science Reviews 22, 33–79.
Kaplan, J.O., Krumhardt, K.M., Zimmermann, N., 2009. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews. 28, 3016–3034.
Knox, J.C., 1972. Valley alluviation in Southwestern Wisconsin. Annals Association of American Geographers 62, 401–410.
Knox, J.C., 1977. Human impacts on Wisconsin stream channels. Annals Association of American Geographers 77, 323–342.
Knox, J.C., 1987. Historical valley floor sedimentation in the Upper Mississippi Valley. Annals Association of American Geographers 77, 224–244.
Knox, J.C., 2006. Floodplain sedimentation in the upper Mississippi Valley: natural versus human accelerated. Geomorphology 79, 286–310.
Kortyny, L.M., Bazhenova, O.I., Martianova, G.N., Ilyicheva, E.A., 2003. The influence of climatic change and human activity on erosion processes in sub-arid watersheds in southern East Siberia. Hydrological Processes 17, 3181–3193.
Lal, R., 1988. Soil erosion by wind and water: problems and prospects. In: Lal, R. (Ed.), Soil Erosion Research Methods. Soil and Water Conservation Society, Ankeny, Iowa, pp. 1–6, 244.
Lang, A., Bork, H.-R., Mäckel, R., Preston, N., Wunderlich, J., Dikau, R., 2003. Changes in sediment flux and storage within a fluvial system: some examples from the Rhine catchment. Hydrologic Processes 17, 3321–3334.
Liu, L., 2004. The Chinese Neolithic: Trajectories to Early States. Cambridge University Press, Cambridge, UK & NY.
Luzzadder-Beach, , Beach, T., 2009. Arising from the wetlands: mechanisms and chronology of landscape aggradation in the Northern Coastal Plain of Belize. Annals of the Association of American Geographers 99(1), 1–26.
Lyell, C., 1849. A Second Visit to the United States of North America. John Murray Co., London.
Macklin, M.G., Lewin, J., 1993. Holocene river alluviation in Britain. Zeitschrift für Geomorphologie 88, 109–122.
Macklin, M.G., Lewin, J., 2003. River sediments, great floods and centennial-scale Holocene climate change. Journal of Quaternary Science 18, 101–105.
Macklin, M.G., Lewin, J., 2008. Alluvial responses to the changing Earth system. Earth Surface Processes and Landforms 33, 1374–1395.
Mann, C.C., 2005. 1491: New Revelations of the Americas Before. A. A. Knopf, Columbus. N.Y., 465 pp.
Marsh, G.P., 1864. Man and Nature; or, Physical Geography as Modified by Human Action. Scribner, NYC, 560 pp.
Martin, P.S., Klein, R.G. (Eds.), 1984. Quaternary Extinctions: A Prehistoric Revolution. University of Arizona Press, Tucson, AZ.
Mather, A.S., Fairbairn, J., Needle, C.L., 1999. The course and drivers of the forest transition: the case of France. Journal of Rural Studies 15(1), 65–90.
Mather, A.S., Needle, C.L., 2000. The relationships of population and forest trends. Geographical Journal 166(1), 2–13.
Matthews, E., 1983. Global vegetation and land use. Journal Climate and Applied Meteorology 22, 474–487.
Mellaart, J., 1975. The Neolithic of the Near East. Thames & Hudson, London.
Merritts, D.J., Walter, R., Rahnis, M, 2011. Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA. The Philosophical Transactions of the Royal Society A 369(1938), 976–1009.
Milliman, J.D., Qin, Y.S., Ren, M.E., Saito, Y., 1987. Man's influence on the erosion and transport of sediment by Asian rivers: the Yellow River (Huang He) example. Journal of Geology 95, 751–762.
Montgomery, D.R., 2007. Dirt: The Erosion of Civilizations. University of California Press, Berkeley, 285 pp.
Moore, A.M.T., 1982. Agricultural origins in the near East: a model for the 1980s. World Archaeology 14(2), 224–236.
Moore, A.M.T., Hillman, G.C., Legge, A.J., 2000. Village on the Euphrates. From Foraging to Farming at Abu Hureyra. Oxford University Press, Oxford.
Nevle, R.J., Bird, D.K., 2008. Effects of syn-pandemic fire reduction and reforestation in the tropical Americas on atmospheric CO_2 during European conquest. Palaeogeography, Palaeoclimatology, Palaeoecology 264(1–2), 25–38.

Olley, J.M., Wasson, R.J., 2003. Changes in the flux of sediment in the Upper Murrumbidgee catchment, Southeastern Australia, since European settlement. Hydrological Processes 17, 3307–3320.

Olley, J.M., Murray, A.S., Mackenzie, D.H., Edwards, K., 1993. Identifying sediment sources in gullied catchments using natural and anthropogenic radioactivity. Water Resources Research 29(4), 1037–1043.

Peters, R.L., Lovejoy, T.E., 1990. Terrstrial fauna. In: Turner, II B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (Eds.), The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge, UK, Chapter 20, pp. 353–369.

Phillips, J., 2003. Alluvial storage and the long-term stability of sediment yields. Basin Research 15, 153–163.

Pimentel, D., Harvey, C., Resosudarmo, P., et al., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–1123.

Pohl, M.D., Pape, K.O., Jones, J.G., et al., 1996. Early agriculture in the Maya lowlands. Latin American Antiquity 7(4), 355–372.

Pretty, J.N., 2008. Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B 363(1491), 447–465.

Price, T.D., 2000. Europe's first farmers: an introduction. In: Price, T.D. (Ed.), Europe's First Farmers. Cambridge University Press, Cambridge, UK, pp. 1–18.

Pringle, H., 1998. The Slow Birth of Agriculture. Science 282, 1446.

Redman, C.L., 1978. The Rise of Civilization. Freeman, San Francisco.

Redman, C.L., 1999. Human Impact on Ancient Environments. University of Arizona Press, Tucson, 239 pp.

Ren, M., Zhu, X., 1994. Anthropogenic influences on changes in the sediment load of the Yellow River, China, during the Holocene. The Holocene 4, 314–320.

Renfrew, C., 1987. Archaeology and Language. The Puzzle of Indo-European Origins. University of Cambridge Press, Cambridge.

Richards, M., 2003. The Neolithic invasion of Europe. Annual Review of Anthropology 32, 135–162.

Rius, D., Vannière, B., Galop, D., 2009. Fire frequency and landscape management in the northwestern Pyrenean piedmont, France, since the early Neolithic (8000 cal. BP). The Holocene 19(6), 847–859. http://dx.doi.org/10.1177/0959683609105299.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology Books, Pagosa Springs.

Rowley-Conwy, P., 2004. How the West was lost: a reconsideration of agricultural origins in Britain, Ireland and southern Scandinavia. Current Anthropology 45(S4), 83–113.

Ruddiman, W.F., 2003. The anthropogenic greenhouse era began thousands of years ago. Climatic Change 61, 261–293.

Ruddiman, W.F., Ellis, E.C., 2009. Effect of per-capita land use changes on Holocene forest clearance and CO2 emissions. Quaternary Science Reviews 28, 3011–3015.

Saito, Y., Yang, Z., Hori, K., 2001. The Huang He (Yellow River) and Changjiang (Yangtze River) deltas: a review on their characteristics, evolution and sediment discharge during the Holocene. Geomorphology 41, 219–231.

Sauer, C.O., 1952. Agricultural Origins and Dispersals. George Grady Press, The American Geographical Society NY, 110 pp.

Temple, R.K.G., 1986. The genius of China. 3000 Years of Science, Discovery and Invention. Simon and Schuster, New York, ISBN: 0671620282.

The Royal Society. 2009. Reaping the Benefits; Science and the Sustainable Intensification of Global Agriculture. The Royal Society, London, UK.

Tilman, D., 1998. The greening of the green revolution. Nature 396, 211–212.

Trabucco, A., Zomer, R.J., Bossio, D.A., van Straaten, O., Verchot, L.V., 2008. Climate change mitigation through afforestation/reforestation: a global analysis of hydrologic impacts with four case studies. Agriculture, Ecosystems & Environment 126(1-2), 81–97.

Trimble, S.W., 1974. Man-induced soil erosion on the Southern Piedmont, 1700-1970. Soil and Water Conservation Society of America, Ankeny, IA.

Tringham, R., 2000. Southeastern Europe in the transition to agriculture in Europe: bridge, buffer, or mosaic. In: Price, T.D. (Ed.), Europe's First Farmers. Cambridge University Press, Cambridge, UK, pp. 19–56.

Troeh, F.R., Hobbs, J.A., Donahue, R.L., 2003. Soil and Water Conservation. Prentice Hall, Upper Saddle River, NJ, 632 pp.

United Nations. 2010. World population prospects: the 2010 revision population database. http://esa.un.org/unpd/wpp/index.htm

van Andel, T.H., Zangger, E., Demitrack, A., 1990. Land use and soil erosion in prehistoric and historical Greece. Journal of Field Archaeology 17(4), 379–396.

van Andel, T.H., Runnels, C.N., 1995. The earliest farmers in Europe. Antiquity 69, 481–500.

van Andel, T.H., Runnels, C.N., Pope, K.O., 1986. Five thousand years of land use and abuse in the southern Argolid, Greece. Hesperza 55, 103–128.

Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., Ocakoglu, F., 2011. Sediment yield in Europe: spatial patterns and scale dependency. Geomorphology 130(3-4), 142–161.

Vavrus, S., Ruddiman, W.F., Kutzbach, J.E., 2008. Climate model tests of the anthropogenic influence on greenhouse-induced climate change: the role of early human agriculture, industrialization, and vegetation feedbacks. Quaternary Science Reviews 27, 1410–1425.

Vita-Finzi, C., 1969. The Mediterranean Valleys: Geological Changes in Historical Times. Cambridge University Press, Cambridge.

Walling, D., 1983. The sediment delivery problem. Journal of Hydrology 65, 209–237.

Walter, R.C., Merritts, D.J., 2009. Natural streams and the legacy of water-powered mills. Science 319(18), 299–314.

Wasson, R.J., Mazari, R.K., Starr, B., Clifton, G., 1998. The recent history of erosion and sedimentation on the Southern Tablelands of southeastern Australia: sediment flux dominated by channel incision. Geomorphology 24, 291–308.

Wen Huanran, et al., 1995. Zhongguo Lishi Shiqi Zhiwu yu Dongwu Bianqian Yanjiu. (Studies on Changes in Plants and Animals in China During Historical Times.). Chongqing Chubanshe, Chongqing, [Cited by Elvin, 2004].

Whitmore, T.M., Turner, II B.L., 2002. Cultivated Landscapes of Middle America on the Eve of Conquest. Oxford University Press, New York.

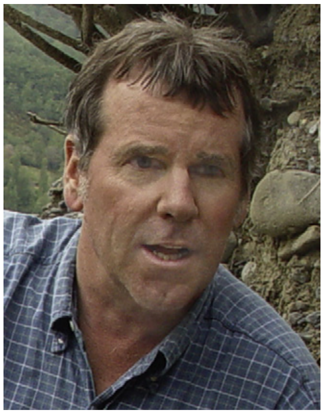
Williams, M., 1990. Forests. In: Turner, II B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (Eds.), The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge, UK, Chapter 11, pp. 179–201.

Xu, J., 2003. Sedimentation rates in the lower Yellow River over the past 2300 years as influenced by human activities and climate change. Hydrological Processes 17, 3359–3371.

Yi, S., Saito, Y., Oshima, H., Zhou, Y., Wei, H., 2003. Holocene environmental history inferred from pollen assemblages in the Huang He (Yellow River) delta, China: climatic change and human impact. Quaternary Science Reviews 22, 609–628.

Zhang, R., Xie, S., 1982. A discussion of the main cause of the continuous aggradation of the lower Yellow River based on the sedimentation of the old channel of the Ming to Qing dynasties Yellow River. Sediment Research 2, 11–22(in Chinese); cited by Xu, 2003.

Biographical Sketch



L. Allan James is a Professor in the Department of Geography at the University of South Carolina, Columbia, SC. He received an undergraduate degree in geography at the University of California, Berkeley, master's degrees in water resources management and geography at the University of Wisconsin, Madison, and a PhD in geography and geology at the University of Wisconsin, Madison. His primary research interests are in river and watershed science, fluvial geomorphology, and linking human impacts in river systems to historical sedimentation and flood hydrology. He is also engaged in research on human–environment interactions, water resources, and hydrogeomorphic applications of geographic information (GI) science. He has allied interests in geomorphometry and remote sensing applied to historical change detection, especially to fluvial systems and gullies, and mapping geomorphic evidence of former glaciations in the Sierra Nevada, CA. He has served as chair of the Geomorphology Specialty Group of the Association of American Geographers, panelist to the Geomorphology and Quaternary Science Division of the Geological Society of America, founding editor of the GSG_AAG web page, and national councilor to the AAG.