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Changing Times

The Holocene Legacy

William R. Dickinson

Environmentalism has become a powerful force in global scientific and political affairs. Part of its influence stems from the truism that a viable environment is not just a lofty ideal but a practical necessity for the future of humanity. Another part comes from a reawakening of prehumanistic thoughts that humanity is not necessarily the sole measure of all things. These two threads of modern environmental thinking underscore the age-old question of the place of humankind in nature. Alternate concepts about the relationship of human beings to nature depend largely on philosophical attitudes independent of any external reality, but accurate perception of environmental history is a prerequisite for valid environmental concepts. Understanding how the global environment we observe today has evolved from antecedent conditions is indispensable as part of the basis for guiding future environmental management. An adequate appraisal of environmental history must include a geological perspective.

Holocene Time

In geological parlance, the time since the last great Pleistocene ice sheets melted away is termed the Holocene, which has not been a long chapter in the history of the Earth. Together, the Pleistocene and Holocene make up the Quaternary period, marked by waxing and waning of polar glaciers. The round number of 10,000 years ago is commonly taken to mark the beginning of Holocene time, although improved calibration of radiocarbon dating indicates that 11,500–11,600 years is a better estimate (see Figure 1). The time span of the postglacial world has been surprisingly brief, and in geological terms, most modern environments have a short time depth.

The glacial world of the Pleistocene was dramatically different from our own. At times of glacial maxima, the most recent of which was only 20,000–22,000 years ago, great ice sheets covered most of North America as far south as Seattle, Chicago, and New York City. In Europe (see Figure 2), a curved line connecting the capital cities of London, Berlin, Warsaw, and Moscow delineates the approximate ice limit, with a variety of those locales overrun by ice during periods of intense glacial advances and lying just beyond the ice limit during lesser advances. At such times, the Baltic Sea and the shallower part of the North Sea between Great Britain and Norway disappeared beneath ice cover that crowned Scandinavia, and northern Europe closely resembled modern Greenland in its climate and overall aspect.[1]

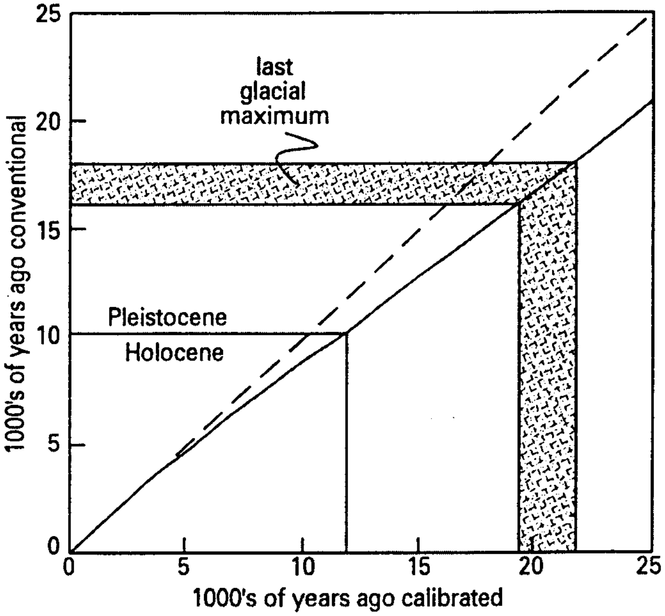
When Pleistocene ice was in place, the geographic tracts of North America and Europe that are now temperate grasslands and mixed forests were very different places. Tundra and open steppe occupied most of Europe south to the Mediterranean littoral, and a belt of tundra fringing the ice fields in North America met a broad band of coniferous forest, much like the modern Siberian taiga to the south, extending across the midsection of the United States and reaching down perhaps as far as the southern borders of Tennessee and Oklahoma (see Figure 3). None of the familiar landscapes of Euroamerican tradition, nor of Amerindian tradition, existed at the beginning of Holocene time.

Continental and island shorelines were also impacted in dramatic fashion by Pleistocene glaciation, and the direct effects extended worldwide because the continental ice sheets drew water from all the oceans. During peak glaciation, global sea level stood an estimated 410 feet lower than today (see Figure 4). Modern shorelines, together with their associated estuaries, tidal flats and coral reefs, cannot have occupied their present positions for more than a few thousand years. Coastal ecosystems have been forced to migrate staggering distances since the waning of Pleistocene glaciers began to drive the postglacial rise in global sea level, termed *eustasy* by geologists. Sea level was still perhaps 300 feet below its modern position as recently as 15,000 years ago. Typically, the postglacial biotic migrations were much greater than just the distances landward from synglacial positions of the strandline directly offshore. Climatic zones and water masses shifted latitude as glaciation waned, meaning that many littoral species also had to move hundreds of miles laterally along coastlines to arrive at congenial Holocene environments.

Coastlines near regions of Pleistocene glaciation paradoxically experienced an opposite change in relative sea level when the ice sheets melted. Removal of the weight of thick glacial ice caused the landscape to be uplifted at rates that outpaced the eustatic rise in sea level. Geologists term such postglacial uplift *isostatic rebound* because it stems from changes in isostasy, which refers to the processes that balance rock masses at different elevations above the fluid interior of the Earth. Because of isostatic rebound, Pleistocene paleoshorelines in formerly glaciated areas are now exposed far inland or well up the flanks of coastal mountain ranges. Along the Pacific coast of Canada, for example, paleoshorelines of Pleistocene age stand 150–500 feet above modern sea level. The isostatic rebound was time-delayed, because it could only be accomplished through slow worldwide flowage of viscous mantle lying below the stiff crust of the Earth.

Simultaneously, continental margins distant from regions of Pleistocene glaciation were tilted downward toward adjacent ocean basins when the weight of glacial meltwater was added to seawater volumes. Even at sites far removed from circumpolar ice masses, isostatic changes in local relative sea level resulting from the additional weight of ocean water left a subtle imprint on coastal landscapes. Regional isostatic adjustments to deglaciation affected sea level much less than the eustatic change in average global sea level resulting from the addition of glacial meltwater, but were quite important locally. For most Pacific islands, postglacial isostatic effects led to a relative highstand of five to eight feet in regional sea level during mid-Holocene time, peaking perhaps 4,000 years ago.[3]

Figure 1. Conventional vs. calibrated radiocarbon ages. Dashed line is locus of equal ages. Solid line is actual approximate correlation of conventional and calibrated ages, with the latter derived from tree-ring chronologies for Holocene time and from independent uranium/thorium isotopic dating for Pleistocene time.[2]

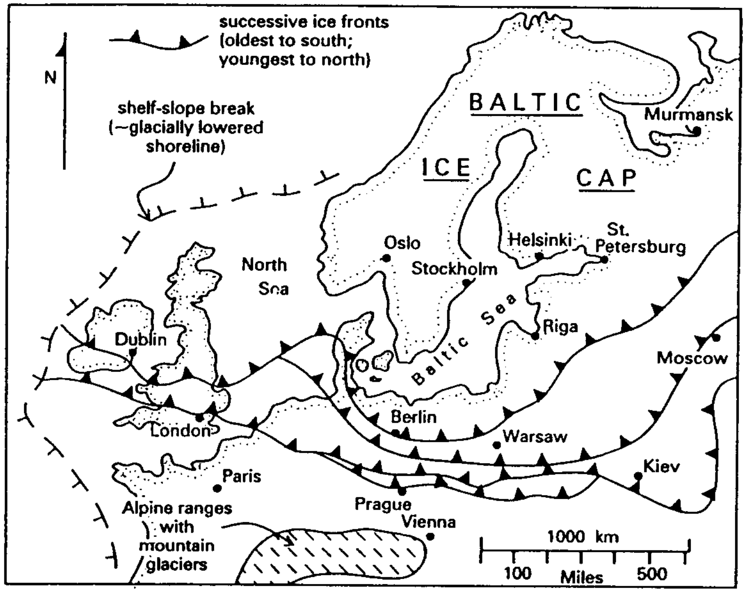


Holocene Humankind

The remarkable changes in the physical environments of the Earth during the Holocene have been more than matched by the cultural evolution of humankind. At the end of the Pleistocene, none of our ancestors had access to any tools more sophisticated than could be fashioned by hand from pieces of stone, bone, or wood. Virtually all the technology upon which we now rely has been developed during Holocene time in less than five hundred human generations. Human civilization as it exists was produced by opportunistic adaptations of the human species to emerging postglacial environments.[4]

Given the fact that glaciations have waxed and waned at least a dozen times, and probably a score or more times, for well over a million years, the Holocene can be

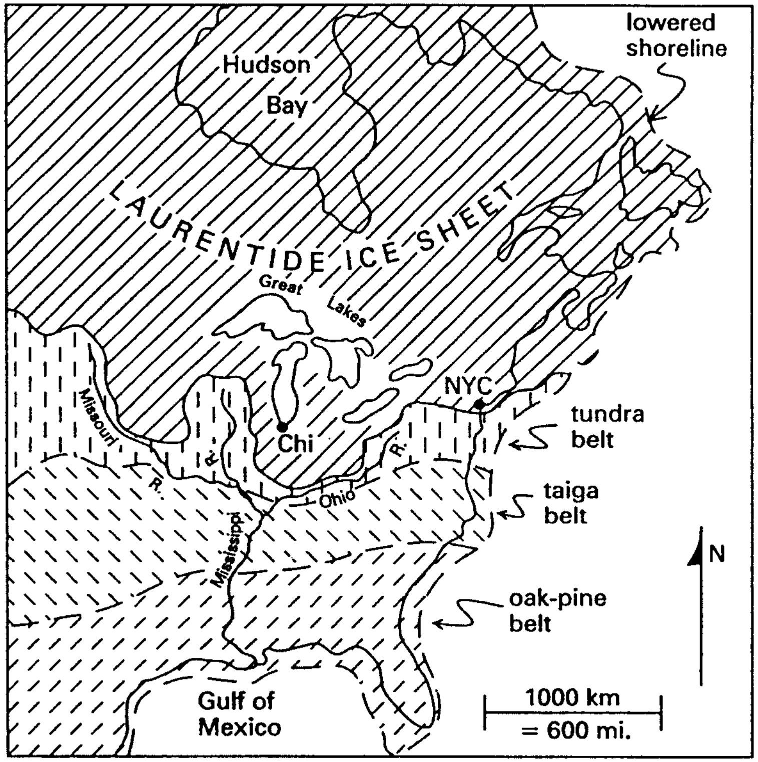
Figure 2. Southern limits of Pleistocene glaciations in northern Europe. Successive ice fronts mark southward extent, at various times during the Pleistocene epoch, of the vast continental glacier that blanketed the entire landscape farther north, including marine shelves exposed to the air by eustatic drawdown of sea level.[5]



viewed as just the latest of a long series of interglacial time intervals, and destined like the others to be succeeded in due course by yet another glaciation. In one crucial respect, Holocene time has been unique among interglacial intervals. It is the first interglaciation during which anatomically modern humans existed (see Figure 5). Whether modern human beings emerged only 50,000 years ago, as many have thought, or have existed for nearly 100,000 years, as some now argue, none were present during the last interglaciation approximately 125,000 years ago. Interglacial climatic conditions analogous to historical experience lasted only 12,000 to 20,000 years, not markedly longer than the duration of the Holocene to date.[6]

The impact of the emerging human species on global environments during the last glaciation is moot because the conditions that prevailed then were so extensively modified by the climatic transition to Holocene time. As modern Holocene environments evolved from Pleistocene precursors, people of essentially modern aspect, driven by familiar impulses, were active on most parts of the continental landmasses from the very initiation of postglacial conditions. The same cannot be said of oceanic islands or polar regions that people were unable to occupy before acquiring adequate maritime technology and the skills to survive under extreme climatic conditions. Exploration and settlement of the Pacific islands of Oceania, remote from the Australian and Asian landmasses, did not begin until approximately 3,500 years ago. The peopling of Oceania by the Polynesians and their ancestors is one of the great sagas of prehistory but was delayed until after the middle of Holocene time.[8]

Figure 3. Environmental belts of eastern North America at peak glaciation—20,000 years ago; taiga is spruce-pine evergreen forest analogous to the forests of modern Siberia; varied broadleaf tree species accompanied the oak-pine woodlands farther south.[7]



In most global environments, the Holocene landscape never established itself without human influence. Landscapes and cultures coevolved over the same intervals. Knowing the propensity of human beings to alter their surroundings indicates that the nature of Holocene environments was in part determined by human activities, even as people learned to adapt to them and exploit them for their own purposes. The environmental impact of human dispersal through Oceania over several millenia before European contact with island cultures is instructive. In island group after island group, human arrival was followed closely by environmental alteration involving forest clearance, with consequent upland erosion and downstream sedimentation, or replacement of virgin forest by agroforest developed through human silviculture.[9]

The s[illegible]tive notion that the world was a pristine place before people gradually hewed their way into it, culminating their impact with the environmental insults of the industrial age, is out of focus. The landscapes of yesteryear, so beloved in our cultural memories, did not spring up wholly untouched by human hands. Nor should we view overt human manipulation, or inadvertent alteration, of the environment during prehistory as necessarily or uniformly deleterious to ambient conditions. The postglacial Holocene world was inherently in flux, and successful aboriginal cultures must have adjusted their environmental practices to modes that improved, rather than reduced, resources for subsistence.

Shoreline Evolution

The glacial drawdown in global sea level has had lingering effects through much of Holocene time. In the protohistoric period of 7000–9000 BC, when many civilizations of the ancient world had their first tentative beginnings, global sea level was still more than seventy-five feet below its modern level, not rising to within fifteen feet of its present stand until about 5,000 years ago (see Figure 4). Massive encroachment of the sea on almost all landmasses was the rule during the first half of Holocene time. During the Pleistocene lowstand, the entire Persian (or Arabian) Gulf, down to the Strait of Hormuz, was dry land, though perhaps dotted with lakes, and the ground where ancient Mesopotamia later thrived stood roughly 600 miles from the open marine waters of the Indian Ocean. Following the postglacial eustatic rise in sea level, some 250 miles of riverine lowlands along the Tigris-Euphrates valley of the Fertile Crescent were flooded by saltwater as recently as 6,000 years ago, to be reclaimed later as dry land by fluvial aggradation. Even the seaport of Charax, founded by Alexander the Great, now lies ninety miles from open water.[10]

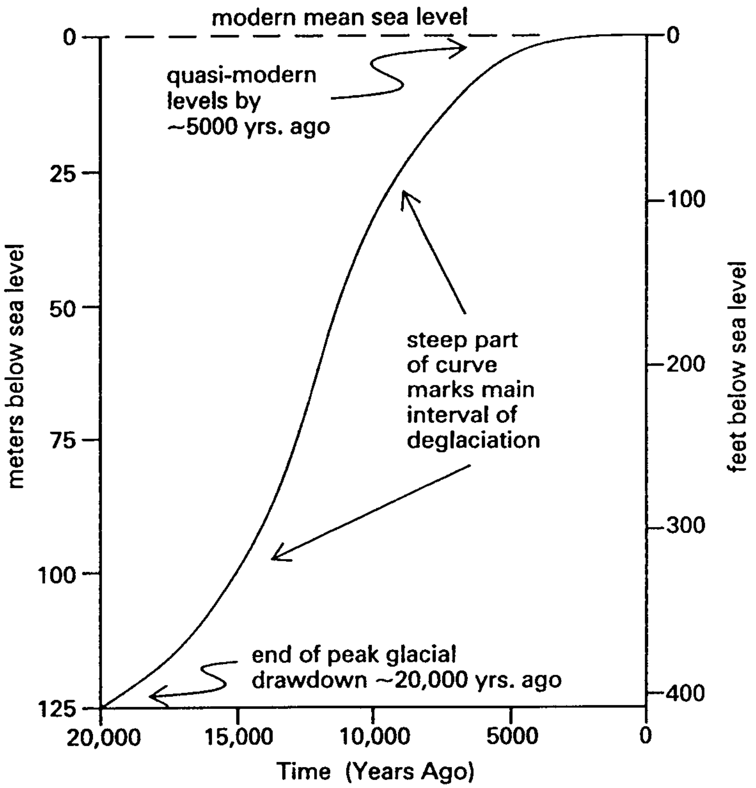
As the rate of rising sea level gradually slowed, rivers began to build deltas from retreating shorelines into the encroaching seas. This process became important after about 6000 BC, and led to dramatic impacts on coastal landscapes. The Holocene Mississippi River has extended its delta about 150 miles into the Gulf of Mexico, adding more than 12,000 mi² of land surface south of Baton Rouge to the coastal lowlands (see Figure 6). All the resulting diversity of levee and marshland, with its resident aquatic wildlife, occupies an area that was drowned under shelf sea at the dawn of Old World civilizations. In Egypt, the arcuate front of the Nile delta, with its classic deltoid shape, has prograded steadily into the Mediterranean at a mean rate of approximately one kilometer per century over the last 5,000 years.[11]

Mississippi Delta

Nile delta

Recent human modifications to river regimens have now begun to reverse delta growth in key instances. Essentially all deltas subside slowly from their isostatic loads on the Earth's crust and from the time-delayed compaction of delta sediment accumulations. Without continuing deltaic sedimentation, seawater encroachment is inevitable along delta margins. Upstream dams and dense networks of irrigation or drainage canals that trap sediment inhibit delta growth, as does the dredging of ship channels to funnel riverine sediment directly into deep water offshore. As a result, the Mississippi delta is currently losing subaerial delta plain at a rate nearly ten times the average rate of outbuilding over the past 8,000 years. Accelerated erosion of the front of the Nile delta has been underway for the past century, with current rates of shoreline retreat locally exceeding 250 feet per year in some years.[13]

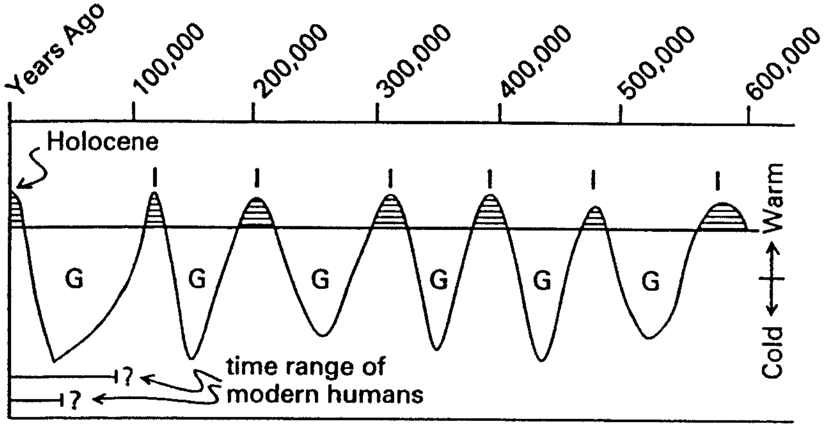
Figure 4. Approximate latest Pleistocene and Holocene rise in mean global sea level from eustatic change in seawater volume as deglaciation transferred mass from circumpolar ice fields to the world ocean.[12]



The signal changes in worldwide strandlines during the Holocene and the comparable changes that repeatedly accompanied successive glacial-interglacial transitions throughout the duration of the Pleistocene had surprisingly little net effect on strandline biotas. We know little about shoreline faunas during Pleistocene lowstands in sea level, because drawdown in sea level placed them at sites now underwater and far offshore. From study of successive interglacial faunas, it is clear that Quaternary extinction rates of coastal marine organisms were generally unexceptional. Coastal life evidently endured the stress of repeated migration remarkably well.[14]

Analysis suggests that species survived as habitats migrated with changing times because each individual species shifts location independently, in response to its own unique tolerances and requirements, rather than as part of intact coadapted

Figure [illegible] Principal climatic fluctuations over the past half million years, between glacial (G) and interglacial (I) conditions, in relation to the evolutionary emergence of anatomically modern human only 50,000 to 100,000 years ago.[15]



biotic communities. This picture of flux suggests that no modern coastal ecosystem is yet fully adjusted to current conditions. Each may represent a metastable state still in process of adjusting to postglacial changes in surroundings, drawing on species pools available on nearby marine shelves as local conditions vary. The living biotas of modern coastal ecosystems are likely ephemeral associations caught at an arbitrary point along a spectrum of gradual change. If lasting stability of habitat and biota has been reached along any present coastline, such a state of affairs could not possibly have an antiquity of more than a few thousand years.[16]

Terrestrial Surface

As Pleistocene ice masses retreated, massive biotic migrations also swept across much of the Holocene land surface as global climates changed. In Japan, far from any continental ice sheets but joined into one elongated island by drawdown in sea level during full glacial times, the extensive conifer forests of modern-day Hokkaido on the north replaced preexisting Pleistocene tundra, and the existing deciduous and evergreen broadleaf forests of the more southerly Japanese islands in turn replaced conifer forest that prevailed during glacial times.[17]

In the United States, stark latitudinal changes in vegetative cover were prominent during the transition from Pleistocene to Holocene conditions (see Figure 3). In the east, the southern limit of abundant spruce retreated from the Ohio Valley to the Canadian taiga north of the Great Lakes, and an irregular boundary between coniferous and deciduous forest migrated northward in its wake. In the west, during the last glaciation, mountain ranges of the Great Basin now cloaked by pygmy conifers—pinyon and juniper—harbored subalpine conifer forests analogous to those of the modern Rocky Mountains. Similarly, pygmy conifer woodlands characteristic of the modern Colorado Plateau spread southward, during the last glaciation, over much of the present Desert Southwest, which lies at distinctly lower elevations and is now occupied by a mixture of cactus and thornscrub.[18]

As the climate warmed across the American Southwest, plant assemblages in its many mountain ranges migrated upward in elevation by a minimum of at least 1,300 feet and a maximum of fully 2,600 feet to escape increasing temperature and aridity. Pleistocene floras of the intermountain region included unfamiliar plant associations unmatched exactly by any that exist today. Inland biotas experienced individualistic floral migrations, species by species in response to climatic change, that produced uneven displacements of species along both latitudinal and elevational gradients. Present plant communities are evidently ephemeral aggregations controlled by intersecting gradients of floral change. Fossil analogues are not precisely equivalent to the observed communities, and a seeming permanence of observed plant associations in the absence of modern disturbance is probably an illusion fostered by the short time frame of historic observation.[19]

The effects of deglaciation on tropical regions are not fully understood, but ambient temperatures at equatorial latitudes were cooler by approximately 5°C during the last glacial maximum. Available evidence from the Amazon basin indicates that the rain forests so prevalent in the tropics today were more restricted in extent during Pleistocene glaciation, probably broken into less continuous tracts, and composed in part of species adapted to cooler conditions than those that now prevail. Forests were nevertheless widespread in the Amazon basin even at peak glaciation.[20]

Human Influences

Few of the dramatic postglacial changes in global environment escaped the attention of aboriginal humans. Even in the Americas, the last continents to be invaded by the human species, Clovis migrants from Eurasia had spread from Canada to Patagonia, and from Arizona to Boston, by thirteen thousand years ago. Several aspects of the growth of human culture suggest that the impact of human activities became an integral facet of Holocene environmental evolution. Many deltas felt the influence of human occupation almost as soon as they began to grow seaward after 6000 BC. Irrigation in lowland Mesopotamia, which lengthened steadily as the Tigris-Euphrates delta built itself into the Persian Gulf, was practiced at least locally by that time. Rice culture, with its elaborate systems of paddies and terraces, was also born about that time on the delta surfaces of southeast Asia.[21]

Across the wider terrestrial landscape, perhaps no aboriginal impact was greater than the results of broadcast fire. Aboriginal peoples burned the land deliberately,
Fire
to flush small game and drive big game, to deny cover to dangerous animal predators, to clear the growth that might provide cover for enemy ambushes around their settlements and camps, to foster fresh shoots of vegetation that attract favored

game keep woodlands clear of underbrush and easy to traverse, and to keep relatively unproductive woodlands from encroaching upon grasslands richer in usable resources. In precontact Australia, firing of native vegetation was so intensive, to nurture plant communities favored as food by either humans or their game, that native fire practices have been called "firestick farming." When people turned to growing domesticated crops, they resorted even more assiduously to wild fire to clear garden plots and fields, developing a pattern of behavior that survives today as so-called "slash-and-burn" agriculture. Although "slash and burn" has distinctly pejorative connotations for lovers of forested lands, the distributions of different tree species in many present forests owe much to the recurrence of past anthropogenic fires.[22]

Human Impact

Despite decades of general knowledge about the near ubiquity of anthropogenic fire in prehistory, we are still far from comprehending its full import. On the one hand, we acknowledge that fire was the greatest invention of humankind, having in mind its critical application for cooking food, but tending to overlook the fact that it was also the most effective tool of land management available to aboriginal peoples. The grasslands and savannahs of the temperate and tropical regions might owe their very existence to anthropogenic burning, either to remove woodlands or to prevent their initial advance into tundra or steppe inherited from Pleistocene glaciation. Studies throughout the tropics have shown repeatedly that savannah grasslands are dependent for their maintenance, if not their initial creation, on the persistence of anthropogenic fires to combat forest encroachment.[23]

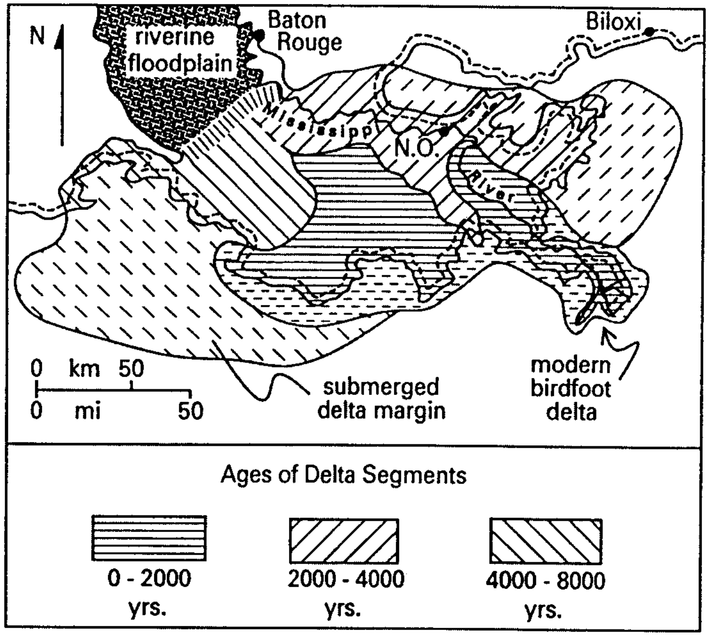
N.Z. experiment

The alternate origin suggested for the development of grasslands is the effect of climate. In some semiarid grasslands, tree growth is precluded by lack of sufficient soil moisture. A fortuitous "experiment" shows, however, that aboriginal peoples were capable of converting forest to open land by deliberate use of wildfire. The arrival of Polynesian migrants roughly a thousand years ago was followed within just a few hundred years by removal of approximately half the previously dense New Zealand forest by repetitive firing to produce grassland, food-rich fernland, and open woodland (see Figure 7).[24]

The impact of wildfire on the nature and density of vegetative cover and the influence of vegetative cover on erosion rates and consequent sedimentation rates suggest that the cumulative effects of anthropogenic fire have exerted a strong control over the evolution of the Holocene landscape. Wildfire could not make mountains or govern the general courses of rivers and streams, but fine-tuning the contours of hill slopes, river bottoms, and stream terraces seems well within the scope of possible results from broadcast burning conducted since the end of Pleistocene time.

Human behavior has also influenced evolving Holocene faunas over much of the world in two salient ways. First, Eurasian domestication of familiar pastoral animals—cattle, goats, horses, sheep, and swine—early in Holocene time affected the viability of wild counterparts over wide areas. Second, the spread of aboriginal peoples to previously unoccupied landmasses, including previously isolated islands, resulted in the extinction or local extirpation of many animals, both mammals and birds, as a result of intensive hunting. The effect was most notable on large animals, the megafauna, with long gestation periods that make population maintenance or recovery difficult in the face of steady attrition. Megafaunal extinctions were not synchronous globally, but phased sequentially from place to place as aboriginal peoples reached different continents and islands. Only in sub-Saharan Africa, where the native fauna coevolved with humankind and prehistoric domestications were a minor factor did a diverse megafauna survive into modern times. By altering fauna, aboriginal peoples might indirectly have affected the flora of many regions as well. In Australia, the extinction of large herbivores following the late Pleistocene arrival of humans to that continent apparently altered the floral balance, leading to conditions that encouraged the setting of wildfires to control vegetation.[26]

Figure 6. Approximate growth pattern, shown as age ranges of key delta segments, of Holocene Mississippi River delta below Baton Rouge, Louisiana (symbols dashed for submerged parts of delta lobes). In detail, time-space relations are more complex than depicted, for more than fifteen successive delta lobes or subdeltas have been distinguished from landscape feature and coring of the delta plain. "N.O." denotes New Orleans, lying just above the head of the youngest component of the delta plain.[25]



On [illegible]y oceanic islands, destruction of habitat by intensive human occupation and anthropogenic introduction of exotic nonhuman predators probably contributed, along with hunting pressure, to the population crashes of the prehistoric past. Within the broad Pacific arena, occupying nearly half the globe, the arrival of Polynesian voyagers over the past few millennia led rapidly to the successive decimation of local bird species, and to other pervasive environmental changes in island group after island group.[27]

Environmental Restoration

Although we live in a world of four dimensions, the dimension of time is unique. We may proceed east or west and north or south, retracing our steps at will, and with the aid of aircraft we can move up or down. But we can only move forward in time, with no hope of ever moving backward. We cannot recover past environments, although we might be able to regenerate them as a means of restoration.

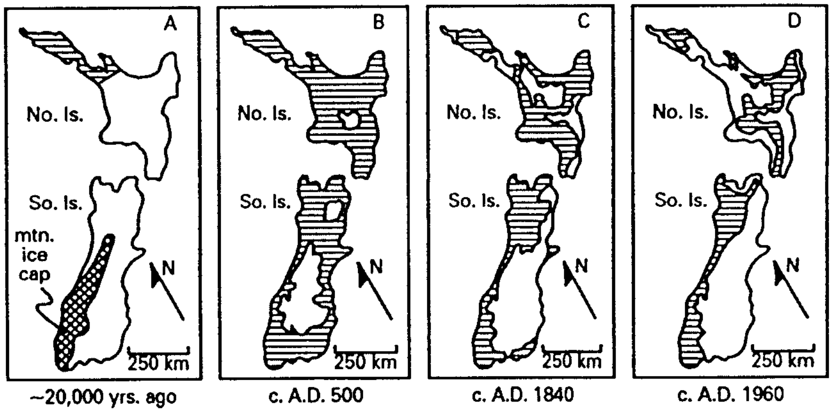
From a geological perspective, the grand sweep of Holocene environmental changes that are largely irreversible make the likelihood of full success in regenerating or restoring lost environments seem quite slim. Returning to where we began at the outset of Holocene time is certainly impossible, and any expectation that a beneficent Nature could restore itself spontaneously to some admired state that existed in the more recent past seems quixotic. Modern industrial civilization and burgeoning population growth have injured the global environment far beyond the perspective or ability of aboriginal peoples to attempt, but the preindustrial environment was already the contingent product of multiple influences, among them the impact of our distant ancestors.

Environmental Management

The burden of environmental management rests inevitably on human shoulders, and a clear sense of environmental history over the full course of Holocene time is a prerequisite for wise environmental decisions. Simply trying as human beings to make no mark on our surroundings may not achieve what we desire. Avoiding some practices, such as burning the landscape, which once were pursued with vigor by aboriginal peoples, introduces wholly new factors into the environmental equation. The popular concept of wilderness as pristine wildland free of any human influence is largely a psychocultural myth, springing more from an uplifting vision of the proverbial Eden than from any historical reality. For charting the future, we will have no substitute for understanding the dynamics of varied ecosystems and the rules of landscape evolution well enough to be able to gauge in advance the results of specific actions that we are able to control.[28]

The challenge to our powers of insight is daunting. In the environmental arena, the temptation is strong to label everything that is "natural" as "good," and anything that seems "bad" as "unnatural," but none of those terms is easy to define in a continuously changing world. Ever since the dawn of Holocene time, when global conditions remotely like those of the present-day first evolved from the ice ages, humans have always impacted the natural environment. Reducing human impact toward a nil level is not only unattainable in practice, but quite literally unprecedented. The task for future human culture is to acquire the knowledge of environmental history and dynamics needed to choose the sorts of human impact that will lead to a posterity of our liking. Faith in a self-regulating and self-restorative nature, independent of humankind, cannot guide us into any environmental harbor where we would wish to moor.

Figure 7. Changing forest cover (ruled areas forested) in New [illegible]aland: A) pre-Holocene at last glacial maximum; B) Holocene prior to arrival of Polynesian migrants; C) after 750+ years of Polynesian occupation; D) after 120 years of European settlement. Anthropogenic firing of the landscape largely accounted for Polynesian forest clearance, with further reductions in forest cover made by European farmers, stockmen, and city builders. During Pleistocene glaciation, owing to drawdown in sea level, New Zealand was actually one large island half again as large as the two present islands combined (not shown as such here because the nature of synglacial vegetative cover on surrounding marine shelves is unknown from any direct evidence).[29]



Holistic History

Existing intellectual traditions have addressed Holocene history from four largely independent standpoints, none adequate alone for a holistic environmental history. From humanism sprang the discipline of history, basing its insights principally on the written record and deriving much of its basic posture from times when even the most rudimentary facts about Pleistocene glaciation and its lingering effects on the Holocene aftermath were unknown. From the social sciences, archaeology came later upon the scene with a primary focus on strictly human prehistory in the sense of cultural events prior to the advent of comprehensive written records. From the physical sciences, Quaternary geology developed as a discipline that was initially almost entirely divorced from considerations of human behavior. From the life sciences, ecologists and biogeographers have evaluated modern and historic biota with increasing sophistication but with minimal attention to prehistoric antecedents, except for documenting evolutionary taxonomic trends.

Each of these disparate approaches leads to only partial understanding of the full tapestry of the Holocene past. Casting off discipline-oriented blinders might allow us to achieve a more integrated vision of Holocene history by working from the premise that environmental and human history are parallel tracks along the same road map across an ever-changing Holocene landscape. Our very ability to forecast the environmental future with any accuracy may depend upon the blending of insights from diverse intellectual wellsprings.

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Notes

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2. For the correlation shown by the curve, see Minze Stuiver and Bernd Becker, "High-Precision Decadal Calibration of the Radiocarbon Time Scale," *Radiocarbon* 35 (Calibration 1993): 35–65; Edouard Bard, Maurice Arnold, R. G. Fairbanks, and Bruno Hamelin, "^{230}Th-^{234}U and ^{14}C Ages Obtained by Mass Spectrometry on Corals," *Radiocarbon* 35 (Calibration 1993): 191–99. Cosmic-ray bombardment of nitrogen in the upper atmosphere produces radiocarbon (a radioactive isotope with a half-life of 5730 years), which is incorporated into the carbon dioxide present in air, and dissolved in waters of oceans and lakes exposed to the atmosphere. Living organisms acquire a characteristic minor fraction of radiocarbon by equilibrating with the carbon dioxide of ambient air or surrounding waters. After death, their body parts lose radiocarbon at its known radioactive decay rate, allowing fossil materials such as wood, charcoal, bone, and shell to be dated (up to a limit of about 40,000 years, after which the amount of remaining radiocarbon is too low to measure with confidence). Conventional and calibrated radiocarbon ages differ because conventional ages are calculated with the assumption of constant atmospheric radiocarbon production, which actually varies through time as fluctuations in the magnetic field of the Earth modulate the intensity of the cosmic-ray flux reaching the atmosphere from outer space, as discussed by Carlo Laj, Alain Mazaud, and J. C. Duplessy, "Geomagnetic Intensity and ^{14}C Abundance in the Atmosphere and Ocean During the Past 50 Kyr," *Geophysical Research Letters* 23 (1 August 1996): 2045–48; H. Kitagawa and J. van der Plicht, "Atmospheric Radiocarbon Calibration to 45,000 yr B.P.: Late Glacial Fluctuations and Cosmogenic Isotope Production," *Science* 279 (20 February 1998): 1187–90. The round number of 10,000 years ago was proposed for the beginning of Holocene time by D. M. Hopkins, "Time-Stratigraphic Nomenclature for the Holocene Epoch," *Geology* 3 (January 1975): 10, and coincides well with the end of the Younger Dryas glacial readvance in conventional (uncalibrated) radiocarbon years. The best current estimate for the beginning of Holocene time is 11,530 calibrated (calendar) years BP (before AD 1950) by Steinar Gulliksen, H. H. Birks, Goran Possnert, and Jan Mangerud, "A Calendar Age Estimate of the Younger Dryas-Holocene Boundary at Krakenes, Western Norway," *The Holocene* 8 (May 1998): 249–59. The chronological implications of calibrating radiocarbon dates for the prehistory of the Americas is discussed by S. J. Fiedel, "Older Than We Thought: Implications of Corrected Dates for Paleoindians," *American Antiquity* 64 (January 1999): 95–115.
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