Choosing appropriate temporal and spatial scales for ecological restoration

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Classic ecological restoration seems tacitly to have taken the Clementsian "balance of nature" paradigm for granted: plant succession terminates in a climax community which remains at equilibrium until exogenously disturbed after which the process of succession is restarted until the climax is reached. Human disturbance is regarded as unnatural and to have commenced in the Western Hemisphere at the time of European incursion. Classic ecological restoration thus has a clear and unambiguous target and may be conceived as aiming to foreshorten the natural processes that would eventually lead to the climax of a given site, which may be determined by its state at "settlement". According to the new "flux of nature" paradigm in ecology a given site has no *telos* and is constantly changing. Human disturbance is ubiquitous and long-standing, and at certain spatial and temporal scales is "incorporated". Any moment in the past 10,000 years that may be selected as a benchmark for restoration efforts thus appears to be arbitrary. Two prominent conservationists have therefore suggested that the ecological conditions in North America at the Pleistocene–Holocene boundary, prior to the anthropogenic extinction of the Pleistocene megafauna, be the target for ecological restoration. That suggestion explicitly assumes evolutionary temporal scales and continental spatial scales as the appropriate frame of reference for ecological restoration. However, ecological restoration should be framed in ecological spatio-temporal scales, which may be defined temporally in reference to ecological processes such as disturbance regimes and spatially in reference to ecological units such as landscapes, ecosystems, and biological provinces. Ecological spatio-temporal scales are also useful in achieving a scientifically defensible distinction between native and exotic species, which plays so central a role in the practice of ecological restoration and the conservation of biodiversity. Because post-settlement human disturbances have exceeded the limits of such scales, settlement conditions can be justified scientifically as appropriate targets of restoration efforts without recourse to obsolete teleological concepts of equilibria and without ignoring the presence and ecological influence of indigenous peoples.

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1. Introduction: classic ecological restoration

The norm or target for ecological restoration seems straightforward and obvious. A given site has been manhandled by the saw, plow, cow or by some other instrument(s) of anthropogenic transformation. It has now been abandoned or retired and by good fortune or foresight it has become a locus for ecological restoration. To what ecological condition should it be restored? Its "original" condition, of course. And how do we know what its "original" condition was? The condition in which it was found at "settlement". This is, after all, exactly what one of the first and arguably the most famous of ecological-restoration projects was all about – the University of Wisconsin (UW) Arboretum and Wild Life Refuge. And none other than Aldo Leopold was the mastermind who conceived its purpose. Leopold (1999a) gave a brief speech at the dedication ceremony of the UW arboretum

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in which he outlined the project and provided a rationale for it. Leopold's statement on that occasion is the first clear articulation of the concept of ecological restoration. Meine (1988, p. 328) sets the scene and quotes the key passage in Leopold's speech:

> On the morning of 17 June 1934, civic leaders and university officials gathered in a barn on the south edge of Madison and officially dedicated the University of Wisconsin Arboretum and Wild Life Refuge. The university had acquired five hundred acres of typical postsettlement Wisconsin farmland: pasturelands, grazed woodlots, plowed prairie, marshes, and fens. Indian burial mounds dotted the perimeter of lake Wingra, on whose southern shores the lands lay. . . . Leopold was one of several speakers that morning. In his talk he described what he and other faculty overseers envisioned for the arboretum. It was not going to be just a collection of trees, like other arboreta, but "something new and different" – a collection of landscapes, a recreation of the land as it once existed. It would be replanted not simply with individual species, but with entire plant communities: prairies, hardwood forest, coniferous forest, marsh. "Our idea, in a nutshell, (Leopold said) is to reconstruct, primarily for the use of the university, a sample of original Wisconsin – a sample of what Dane County looked like when our ancestors arrived here in the 1840s".

At the moment he first defined ecological restoration, Leopold was under the sway of two then prevailing myths: (i) the colonial myth of wilderness; and (ii) the scientific myth of Clementsian equilibrium ecology.

2. The wilderness myth and the equilibrium-ecology myth

In January of the next year, Leopold would join Robert Marshall, Benton McKay, Harvey Broome, Bernard Frank, Harold Anderson, Ernest Oberholtzer, and Robert Sterling Yard to found the Wilderness Society (Meine 1988). In an article published in 1930 in *The Scientific Monthly*, Marshall (1998, p. 86) beautifully articulates the colonial wilderness myth:

> When Columbus effected his immortal debarkation, he touched upon a wilderness which embraced virtually a hemisphere. The philosophy that progress is proportional to the amount of alteration imposed upon nature never seemed to have occurred to the Indians. Even such tribes as the Incas, Aztecs, and Pueblos made few changes in the environment in which they were born. The land and all that it bore they treated with consideration, not attempting to improve it, they never degraded it. Consequently, over billions of acres the aboriginal wanderers still spun out their peripatetic careers, the wild animals still browsed in unmolested meadows, and the forests still grew and mouldered and grew again precisely as they had done for undeterminable centuries.

According to the wilderness myth, the entire Western Hemisphere was in a natural condition, free from significant human influence, when discovered by Columbus. What about the American Indians? Well, yes, they were here already, but there were too few of them and they were either too technologically backward or too environmentally ethical to have a serious impact on the primeval, original ecological conditions persisting in the hemisphere.

In the absence of significant human disturbance, those conditions would remain the same. Sure, trees and other organisms go through life cycles and die, but they are replaced by the same species, generation after generation. And sure, occasionally cataclysmic natural disturbances befall a whole biotic community, but after a series of successional stages, the climax community would reestablish itself. Therefore, overall, the Western Hemisphere remained unchanged for "undeterminable centuries". This is the ecological equilibrium myth in a nutshell.

Frederic Clements was arguably the most influential ecologist of the first half of the twentieth century (Worster 1994). He represented nature in the following way: Each region of the world, which he called a "biome", had a natural plant "formation", which he called the "climax", because it was determined by the climate, which he supposed to be stable (Clements 1916). Climate consists of two principal gradients, moisture and temperature. In North America, for example, the moisture gradient runs from the Sierra rain shadow eastward to the Atlantic: in the dry southwest, a formation dominated by saguaro cactus is the climax; a little farther east the climax is short-grass steppe; still farther east, it's long-grass prairie; from the Mississippi valley on eastward, it's forests. Similarly the temperature gradient determines forest types from southern oak-hickory hardwoods to northern spruce-fir softwoods. Elevation complicates this picture. Going upslope is like going north, and in North America, like going east: the microclimate is cooler and wetter at higher elevations.

In any case, from time to time climax formations experience catastrophic external disturbances – volcanic eruption, wild fire, flood, wind storm. There follows a series of plant formations until the climax is reestablished. Clements (1916) called this process "succession". Moreover, he viewed this process as a kind of organismic development, an ontogeny. It was the climax "sere" that he believed to be a highly integrated superorganism. Ecology is the study of its anatomy, physiology, and metabolism.

> The developmental study of vegetation necessarily rests upon the assumption that the unit or climax formation is an organic entity. As an organism the formation arises, grows, matures, and dies. . . . Furthermore, each climax formation is able to reproduce itself, repeating with essential fidelity the stages of its development. The life history of a formation is a complex but definite process, comparable in its chief features with the life history of an individual plant (Clements 1916, p. 2).

Clements' study area was the prairie just at the time it was being settled by European–American agriculturists (Tobey 1981). To him, they represented an artificial, external disturbance that not only destroyed the climax formation but that also disrupted and forestalled the process of succession back to climax. Thus, from this Clementsian point of view, there appears a sharp distinction between "natural" and "artificial" ecological conditions. The climax formation and the several successional seres leading up to it are natural. Anthropogenic landscapes created by European settlers are artificial.

Most ecologists in the first half of the twentieth century remained under the influence of Clements's theories (Tobey 1981). Many may have rejected his metaphysical idea that ecosystems were superorganisms, but few doubted his teleological concept of ecological succession, terminating in a climax community, which persisted, unless and until destroyed by some external disturbance. Few doubted Clements' hypothesis that after such a resetting of the ecological clock, the site would express the same successional series capped off by the same climax community, if only human beings armed with modern technology would leave it alone. Leopold too remained enthralled by this ecological myth. He wrote:

> The Wisconsin land was stable . . . for a long period before 1840 (the year "settlement" began). The pollens embedded in peat bogs show that the native plants comprising the prairie, the hardwood forest, and the coniferous forest are about the same now as they were at the end of glacial period, 20,000 years ago. Since that time these major plant communities were pushed alternately northward and southward several times by long climatic cycles, but their membership and organization remained intact. Thus in one northward push the prairie once reached nearly to Lake Superior; in one southward push the Canadian forest reached to Indiana. The bones of animals show that the fauna shifted with the flora, but its composition or membership likewise remained intact (Leopold 1991, p. 311–312).

3. The myth of Clementsian equilibrium ecology debunked

What's wrong with this picture? The most glaring thing is the putative interval between the present and "the end of the glacial period". When Leopold wrote this in 1944, the time back to the last glaciation was believed to be twice the actual interval (McIntosh 1985). On a clear day 20,000 years ago, from where Leopold stood at the dedication ceremony of the Wisconsin Arboretum and Wild Life Refuge in 1934, you would see a wall of ice on the northeastern horizon, and to the southwest you might see a herd of woolly mammoths. Also, faithfully reflecting the embryonic state of palynology in the 1940s, he tells us that the pollen record indicates that the Holocene biotic communities of Wisconsin – both prairies and forests – moved northward and southward as units. This, as Arthur Tansley notes, was also an idea expressly theorized by Clements:

> If a continental ice-sheet slowly and continuously advances or recedes over a considerable period of time all the zoned climaxes which are subjected to the decreasing or increasing temperature will, according to Clements's conception, move across the continent "as if they were strung on a string", much as the plant communities zoned around a lake will move towards the centre as the lake fills up (Tansley 1935, p. 302)

Contemporary palynology paints a very different picture. Plant species migrated from Pleistocene refugia from different directions at different rates (West 1964; Davis 1984). This evidence supports the "individualistic" alternative to Clementsian holism, first championed by Henry Gleason (1926), a contemporary of Clements, in the first quarter of the twentieth century. Gleason was so thoroughly ignored that he eventually dropped out of ecology and pursued another line of work (McIntosh 1975). According to Gleason (1926), what appears to be a tightly integrated ecological unit, is actually just an ill-defined, accidental assemblage of opportunistic organisms that are adapted to similar environmental gradients – such as soil pH, moisture, and temperature.

Presently, the Clementsian "balance-of-nature" paradigm in ecology has been succeeded by a neo-Gleasonian "flux-of-nature" or "shifting" paradigm (Pickett and Ostfeld 1995). What appeared to Clements and most of his contemporaries to be well-defined, self-regulating ecological units of various types, each with its tightly integrated complement of species, now appear to be ever-shifting mix-and-match collections or aggregates of species populations, interacting catch as catch can. Such assemblages or collections change gradually over time, stochastically, as new species chance to arrive and old ones leave. There is no fixed end-point or *telos*, no self-replicating climax community, which is the destination of successional change.

Inherently dynamic biotas are, moreover, subject to routine disturbances, each of which, depending on the spatial or temporal scale of reference, is incorporated into

the system (Pickett and White 1985). For example, at a spatial scale of 1000 hectares and a temporal scale of twenty years, fire in a mixed hardwood forest in the upper midwest is an abnormal and external event. But at a spatial scale of 100,000 hectares and a temporal scale of 200 years, fire in such a forest is "incorporated". With the shift in ecology from the balance-of-nature to the flux-of-nature paradigm, we have added disturbance regimes to energy flow and nutrient cycling as fundamental processes occurring in ecosystems. At appropriately chosen scales, some human disturbances – widely scattered shifting agriculture in moist tropical forests, for example – may also be regarded as incorporated (Sloan and Padoch 1988). Soulé (1995, p. 143) sums up the current world view in ecology quite bluntly:

> The idea that species live in biotic communities is a myth. So-called biotic communities, a misleading term, are constantly changing in membership. The species occurring in any given place are rarely convivial neighbours; their coexistence in certain places is better explained by individual physiological tolerances. . . . Current ecological thinking argues that nature at the level of local biotic assemblages has never been homeostatic. Therefore, any serious attempt to define the original state of a community or ecosystem leads to a logical and scientific maze.

What is the upshot for classical ecological restoration if there is no such thing as the "original" condition of a site? The condition that Dane County, Wisconsin was in at the moment European settlers saw it in the 1840s, to refer back to Leopold's classic articulation of the concept of ecological restoration, is but a snapshot in its ever-changing ecological odyssey. Why seize on that condition as the norm for restoration, rather than its condition at some earlier or, for that matter, later moment?

4. The colonial wilderness myth debunked

Any earlier moment might be just as choice-worthy a norm, but any later moment, an apologist for classical ecological restoration might counter, would not be choice-worthy, because it would be an artificial condition. That invokes the wilderness myth, the core assumption of which is that the preColumbian inhabitants of North America were few in number and had no significant ecological impact. Demographers in the first third of the twentieth century, when Robert Marshall was waxing eloquent about the wilderness condition of the entire Western Hemisphere, had underestimated preColumbian American Indian populations by a factor of ten, because they failed to account for the disastrous effect of Old World diseases on New World peoples (Denevan 1992). If there were ten times more people here "when Columbus effected his immortal debarkation" than Marshall and his contemporaries supposed, the ecological effect of the indigenous peoples of the Western Hemisphere was proportionally greater than they supposed. Nor were American Indians as ecologically passive as Marshall represents them to have been (Kretch 1999). American Indian cultural fire, cultural predation, agriculture, and irrigation had significant and on-going effects on American ecosystems. Charles E Kay (1994) argues that the ecological effects of cultural predation in North America have been seriously underestimated. So much so, that in the preColumbian period, elk were scarce in the Yellowstone, whereas now, protected from human predation, the Yellowstone Elk population has grown to pestilential proportions.

The great unbroken forests in the east and great abundance of game everywhere that European explorers encountered in North America is attributable to the drastic reduction of Indian populations by Old World diseases, which spread from Indian to Indian well in advance of European conquest and settlement of the country (Dobyns 1983). Contemporary demographer William Denevan (1998) estimates that the total human population of North America (including European and African immigrants and Americans of European and African descent as well as remnant populations of American Indians) was 30% smaller in 1750 that it was in 1492. He concludes that because of the demographic debacle caused by Old World pathogens, North America was then in a state of "recovery" from the ecological effects of its indigenous human inhabitants (Denevan 1998). Less tendentiously, we might say simply that it was in a state of transition from one domain of ecological attraction to another (Holling 1992). Indeed, one might argue that, paradoxically, the wilderness condition encountered by European explorers and settlers of North America was itself artificial, created by the depopulation of the continent after its (re)discovery by Columbus.

Leopold's mention of the "end of the glacial period" raises another confounding question. What happened to the mammoths, mastodons, camels, horses, and all the more than thirty other genera of wildlife that were here 20,000 years ago and which all disappeared suddenly at the Pleistocene–Holocene boundary, about 10,000 years ago? Increasingly, the finger points to *Homo sapiens* as the dark angel of their extinction in the Western Hemisphere (Martin and Klein 1984). *Homo sapiens* may have been in the Western Hemisphere before eleven or twelve thousand years ago, but, as we well know from the European rediscovery of the Americas, groups of *Homo sapiens* differ significantly from one another culturally. About eleven or twelve thousand years ago, a group of *Homo sapiens* culturally adapted to big game hunting,

armed with Clovis spear points and atlatl throwing sticks, arrived in the hemisphere from Asia (Martin 1973). In a few centuries thereafter much of the big game they pursued was extinct. The alternative explanation of these extinctions is, of course, sudden climate change (Grayson 1977). But the species that went extinct this time had endured a series of glacial interstadials in which the climate had abruptly shifted from cold to warm. The latest thinking combines the two leading explanations of the mystery of the Pleistocene megafauna extinctions in the Nearctic (McPhee 1999). Climate change stressed them out and a new super-predator, the likes of which they had never experienced before, finished them off.

So how should we revise the picture of the ecological condition of the preColumbian Nearctic painted by Marshall and Leopold? And what are the implications of this revision for ecological restoration? First, the Nearctic was more dynamic than the ecologists of their day supposed. And for ten thousand years or so before the rediscovery of the Western Hemisphere by European peoples, *Homo sapiens* was not a negligible ecological force. Cultural predation suddenly and radically altered the composition of the fauna of the Nearctic, shortly after the arrival of the Siberian big game hunters at the Pleistocene–Holocene boundary. And by exerting unrelenting hunting pressure on the surviving fauna and setting fire to forests and grasslands, *Homo sapiens* became a keystone species in the Nearctic (Kay 1995). Therefore, the pre-settlement condition of an area appears to be a questionable target or norm for ecological restoration. Indeed, if, as Denevan (1998) notes, European settlers found the land in an abnormally fallow condition, such a condition would be an aberration in an ever-changing, and, for thousands of years, a largely anthropogenic landscape.

5. Pleistocene parks?

Suppose we choose to think that ecological restoration should, indeed, aim to restore a site to its natural condition, and we choose to define its natural condition as relatively free from human influence. But we are persuaded by the so-called "overkill hypothesis", that hemispheric extinctions at the Pleistocene–Holocene boundary are anthropogenic. Then what? Two prominent thinkers register a bold answer: Back to the Pleistocene. First, Michael Soulé (1990, pp 234–235, emphasis added), in his presidential address to the Society for Conservation Biology, commented that:

> Many of the genera of animals that most conservationists would consider alien in North America were actually part of that continent's biota only moments ago in evolutionary time. Thirty seven genera (57 species) of large mammals . . . went extinct just a few thousand years ago in North America, whereas most of their plant prey survived. Some of these animal species still persist in the Old World, and many species of these genera could probably adapt to current North American conditions if they were allowed to "return". For many North American ecologists, the psychological adjustment to biogeographically recombined communities will be painful, but it might be facilitated by the realization that lions, cheetahlike cats, camels, elephants, horses, saiga antelope, yaks, and spectacled bears are native taxa to North America that disappeared very recently. The reintroduction of these large animals will be controversial, but I would not be surprised to read someday that cheetahs are helping to control deer and that mesquite is being "overbrowsed" by rhinoceroses. A cheerful way of viewing such faunal mixing is that it represents the *restoration* to the Nearctic of the great paleomammalian megafauna.

There is the hint of a tongue-in-cheek tone to Soulé's "modest proposal". Soulé I think considers what Aldo Leopold (1949, p. 217) lamented as a "world-wide pooling of faunas and floras" to be inevitable. To make it more palatable we can spin it as "the restoration to the Nearctic of the great paleomammalian megafauna". But Paul S Martin, the leading exponent of the "overkill hypothesis", expresses untempered enthusiasm for a back-to-the Pleistocene reintroduction program. According to Martin and Burney (1999, p. 59, emphasis added),

> In planning New World restorations, conservationists have endowed large mammals of historic time with the exclusive status of hallmarks, or flagships, overlooking the missing large mammals of the late Pleistocene. The animals that the first explorers and settlers saw and wrote about became incorporated in ideas of what constituted American wildness. The viewpoint imposed by a "Columbian Curtain" is unrealistic in evolutionary time. The historic fauna lacks the largest and most representative animals of the continent. Among the more common fossils of the late Pleistocene, which was dominated by equids, camelids, bovids, and especially bones, teeth, and tooth plates of proboscideans, only bison is represented.

Martin and Burney (1999) think big when they think about wildlife restoration. The title of their article is "Bring Back the Elephants", for that is where they suggest we start the restoration to the Nearctic of the great paleomammalian megafauna. They think big in another sense, in a temporal sense as well. The temporal scale on which both Soulé and Martin and Burney think is "evolutionary time". That's why their vision has something of a *Jurassic Park* feel to it. In fact, what Soulé muses about

and Martin and Burney seriously propose is the creation of a system of Pleistocene parks in North America.

6. A question of scale

But is the evolutionary time-scale the appropriate scale for thinking about ecological restoration? I don't think so. We are, after all, struggling to make sense of the concept of ecological restoration – in an ever-changing, dynamic landscape, long influenced by our own species. Higgs (1997) is aware of the problem, but seems to ignore it. According to Higgs (1997, p. 343), "The goal of restoration is to reproduce by whatever means available a predetermined historic or indigenous ecosystem. This goal inscribes the concept of fidelity – that is, a quest to come as close as possible to restoring what existed on a specific site". But which ecological condition that existed on a specific site should be the target of ecological restoration? There are many to choose from. In the quotation that follows, as his use of "so-called" indicates, Higgs (1997) is keenly aware of what he calls "postmodern" (i.e. post-Clementsian) ecology and critiques of the wilderness myth. Nevertheless, he reverts to the classic norms:

> A completely faithful restoration, presumably, is one that exactly replicates *the* ecosystem (i.e. the climax formation?). Hypothetically speaking, we could devise a test whereby ecologists were asked to view the *so-called original ecosystem* alongside the restored version. If no distinction could be made between them, this would be a perfect restoration. . . . A restored ecosystem must strongly resemble the structure and composition of the *so-called natural ecosystem* (Higgs 1997, p. 343, emphasis added).

Higgs (1997, p. 343) admits that "There are several difficulties with this . . . definition of restoration, not the least of which is the idea of nature as a fixed, determinable entity. What vests us with the authority to make claims about the kind of ecosystem to be restored . . .?". Here I try to overcome these difficulties and answer this question. In short, the historic norm for ecological restoration should be selected by reference to ecological, not evolutionary temporal scales. Ecological scales are also useful for accepting some anthropogenic ecological conditions as appropriate norms for ecological restoration and rejecting others.

Hierarchy theory in ecology identifies multiple temporal scales at which ecological processes occur (O'Neill *et al* 1986). For example, nitrogen fixation by rhizobial bacteria occurs at a relatively rapid rate in comparison with ecological succession. Change occurs at all scales. However, we may regard the processes at the higher end of the hierarchy as relatively unchanging or stable if our interest focuses on processes at the middle or lower end. For example, if we are interested in the population cycles of North American arctic mammals, we may regard the latitude and elevation of the boreal biotic provinces of the North American continent as stable, even though the North American plate is slowly drifting to the northwest and is still slowly rebounding from the weight of the retreating ice that once thickly covered its northern half.

So how does hierarchy theory help us think coherently about ecological restoration? It helps us at least to identify appropriate temporal horizons for locating restoration norms or targets. Holling (1992, p. 480) identifies "three approximate scale ranges . . . , each defined by a broad class of processes that dominate over those ranges of scale. The microscales are dominated by vegetative processes, the mesoscales by disturbance and environmental processes, and the macroscale by geomorphological and evolutionary processes". The geological and evolutionary time scales, the scales on which continents migrate and species radiate, are too big. The diurnal, seasonal, and annual time scales on which individual organisms carry out their life processes, such as metabolism, growth, and development are too small.

Taking our clue from Holling (1992), we might measure appropriate temporal mesoscales for norms of ecological restoration by disturbance regimes. For example, for coastal environments we might measure ecological time by the periodicity of disturbance by hurricane-force winds; for riparian environments by the periodicity of floods of various magnitudes, from seasonal fluctuation to the hundred-year flood cycle; for upland forests and grasslands, ecological time might be measured by the frequency of fire. Here, I am only trying to get a feel for what gross range of temporal intervals or units are ecologically meaningful. Let me make an analogy. In the course of a human life, some dynamic processes have little meaning or relevance because they are either too fast or two slow. The rate at which the Grand Canyon historically changed as the Colorado River's rate of erosion kept pace with the increased elevation of the plateau is too slow to register, and the speed of the Krebs cycle is too fast. A human lifetime might be meaningfully organized in half-decades and decades – a person's infancy, childhood, teen years, twenties, thirties, forties, and so on. Indeed, that is just the first scalar range that Holling (1992) characterizes as "vegetative"; it might more inclusively be termed the organismic scalar range. Now what dynamic processes are meaningful and relevant for ecological restoration? By reference to disturbance regimes, I suggest we might meaningfully organize ecological time in terms of centuries.

7. The classic norms of ecological restoration scientifically justified

So that narrows the target window for ecological restoration to the Holocene – to between one and one hundred centuries ago. After the anthropogenic mass megafaunal extinction event in the New World at the Pleistocene–Holocene boundary, new ecological domains of attraction emerged which included the new primate super-predator as a factor in all, and a keystone species in many (Holling 1992). Other species – survivors of the ecological holocaust – adjusted to the new New-World order. Thus, we might justifiably select various historic Holocene biotic communities at a given site as targets for ecological restoration. That selection would be narrowed further by contemporary climatic and edaphic constraints, representing limiting temporal scales – the scales on which climate changes and soils build and erode – between those identified by Holling (1992), the geological-evolutionary and the ecological. A given site, presumably, would not support a biotic community that existed eight or nine thousand years ago when the climate or soil profile was different. Indeed, the more recent historic Holocene biotic communities at a given site seems to be the logical target for restoration, because the site's present climatic and edaphic conditions would more likely support it than some community existing there in the more distant past. I am, as you see, zeroing in on the conventional target and norm for ecological restoration, if not the condition of a site just prior to European–American "settlement", when it was in an abnormal state of "recovery", then in the condition it was in the spring of 1492. I am trying to do so, however, without invoking obsolete ecological assumptions about static equilibria, self-perpetuating, undisturbed climax communities – the "original" condition – or prattling about "pristine", "natural", "wilderness" conditions free of any significant human presence or influence.

Ecological restoration typically favours native species, so much so that to speak of a restoration project consisting of an indiscriminate mix of native and exotic species seems oxymoronic (Jordan *et al* 1987). Indeed, restorationists would not only never think of deliberately employing exotic species in a restoration project, they constantly battle invasive exotics in the on-going management of restored sites (Egan and Glass 1995). But the distinction between native and exotic species is often unclear.

One sees bumper stickers in Florida proclaiming the vehicle's owner to be a native Floridian. It plainly signifies that the claimant was born in Florida, and is not one of the many immigrants to the state. If a native specimen is a specimen that lives in the state where it was born, then by a native species we might mean one that is found in the biological province where it was "born", that is, where it evolved. For example, the several species of kangaroo are native to Australia and exotics elsewhere. And kangaroos evolved in Australia, but not elsewhere (Frith 1969). To insist, however, that a species is only a native in its place of evolutionary origin seems unduly restrictive. Armadillos evolved in South America and migrated to Central America and southern North America, where they are regarded as native, when the Bolivar Trough disappeared and the Panamanian land bridge rose about three million years ago (Marshall 1988). Some species, moreover, have evolved in one place, migrated to another, and gone extinct in their place of evolutionary origin. Camelids are an example (Gauthier-Pilters 1981). They evolved in North America, but no wild populations of camels (or llamas) have existed on that continent for ten thousand years. Few conservationists would argue that a species long residing in a place in which it did not evolve, but long extinct in its place of evolutionary origin, should either be exterminated altogether or exterminated in the place it is now found and reintroduced in its place of evolutionary origin. As these considerations suggest, place of evolutionary origin, far from being a necessary condition of a species nativity, is not even a sufficient condition.

The concept of an exotic species is commonly delimited in terms of natural range and dispersal (Randall 2000). In an Office of Technology Assessment (OTA) report on harmful non-indigenous species in the United States, the following definition of exotic is provided: "the condition of a species being beyond its natural range or natural zone of dispersal" (US Congress, Office of Technology Assessment 1993, p. 53). What "natural" means in this context is unaffected, directly or indirectly, intentionally or unintentionally, by human agency. As the OTA report makes clear, "natural range" means "the geographic area a species inhabits or would inhabit in the absence of significant human influence" (US Congress, Office of Technology Assessment 1993, p. 53). Noss and Cooperrider (1994, p. 392) are equally explicit: "species that occur in a given place, area, or region as the result of direct or indirect, deliberate or accidental introduction of the species by humans, and for which introduction has permitted the species to cross a natural barrier to dispersal". This definition assumes the continued cogency of one important element of the obsolete Clementsian ecological paradigm, the sharp bifurcation of "man" and nature. The distinction between native and exotic species, however, is vitally important, not only to ecological restoration, but to the whole of conservation biology. How can we preserve the distinction, without invoking the scientifically indefensible segregation of human agency from all other kinds of causation?

Once more, considerations of appropriate temporal and spatial scale help us resolve the otherwise ambiguous and

sometimes paradoxical native-exotic distinction. Take a specific example. Are horses and burros natives or exotics in North America? Most wildlife ecologists would classify them as exotics (Rolston 1998; Soulé 1990). But the genus *Equus* evolved in North America and spread from there into Asia, Africa, and Europe (Simpson 1956). It was extirpated from its place of evolutionary origin, in all probability anthropogenically, by the Clovis spearmen, along with the rest of the extinct Pleistocene megafauna of North America (Martin 1973; Soulé 1990). The horse and burro were anthropogenically reintroduced as domestic beasts of burden by the Spanish in the late fifteenth century and soon thereafter established wild (or feral, depending on your point of view) populations in North America (Simpson 1956). If an evolutionary temporal scale is the only one of biological importance, then we would have to reconsider and accept the horse and burro as restored native species. If presence in a place due to human agency were the defining characteristic of an exotic species, then because horses and burros are now in North America thanks to human agency, then, we must consider them to be exotics. That judgment must, however, by the same token, be immediately reversed, because *Equus* was, in all probability, absent in North America due to human agency, until reintroduced by the Spanish. However, if we reject human agency as a scientifically defensible way to distinguish native and exotic species and scale down temporally, and consider the horse in the context of reconfigured Holocene ecological relationships, then the conventional conservationist wisdom that the horse and burro are ecologically disruptive exotics in North America can be justified scientifically – and without ambiguity or equivocation. After the Pleistocene extinctions, which included *Equus* in North America, new ecological domains of attraction emerged. The sudden introduction of the horse and burro threw some of these into chaotic oscillations. In time, of course, *Equus* may be reincorporated in the ecosystems of western North America. But because ecological temporal scales are greater than the organismic scales on which we gauge changes meaningful to us, the horse and burro remain *personae non gratis* for contemporary conservationists and restorationists.

Obviously, appropriate spatial as well as temporal scale is also crucial in distinguishing between native and exotic species. Every earthly species is native to some place on Earth. If our spatial scale of reference is global or planetary, then every earthly species is native to every earthly place. What more circumscribed spatial scale is appropriate for discriminating between native and exotic species? The back-to-the-Pleistocene advocates also think too big spatially, that is, they think in continental terms. Ecological spatial scales – patches, landscapes, biotic provinces – however are more appropriate, depending on the species in question. Some wide-ranging "cosmopolitan" species are native to many bioregions on several continents. The wolf is an example (Harrington and Paquet 1982). At the opposite extreme, some species are endemic, that is, native to only a very restricted place. The Devil's Hole pupfish is an example (Pister 1974). Considering intermediate spatial scales, the brown-headed cowbird, a nest parasite, is native to North America, but an alien in many North American bioregions (Brittingham and Temple 1983). Thus, for purposes of ecological restoration, it should be considered a noxious exotic to be eradicated in those areas outside its historic Holocene range. The southern magnolia is native to Texas, but not to all of Texas, a very large and ecologically diverse state (Wasowski 1988). Ecological restorationists in southeast Texas would do well to plant the species in restoration projects there, but not in those in other parts of the state.

The concept of a "naturalized" species seems to be a cross between the concepts of native and exotic species. According to Westman (1990, p. 252), "a naturalized species is defined as one that has been present so long among its associates that mutual coexistence (and dispersal) over a significant duration is demonstrated . . . (but) it is unclear how long a species must be naturalized before it can be considered native". What is abundantly clear is that Westman regards a species status as native, exotic, or naturalized to be determined not by reference to its place of evolutionary origin or vector of dispersal, but by reference to time. It is equally clear that both "present" (in a place) and "significant duration" in his definition of "naturalized" implicitly refer to ecological spatial and temporal scales. Besides being present in a place for a fairly long time (in ecological measures of time), but not long enough to be regarded as native, an additional ecological consideration is necessary, however, to distinguish a naturalized species from a persistent noxious exotic. As Westman here indicates without elaboration, for a species to qualify as naturalized also requires "mutual coexistence" with its adopted native (and fellow naturalized) associates. A naturalized species, in other words, is a well-established non-native that is also a well-behaved citizen of its adopted biotic community. That is, at the very least, to qualify as naturalized a non-native species must not displace or extirpate the native species in its adopted habitat, either by competitive exclusion or depredation and, more positively, if it turns out to be of use as habitat or food for the fellow citizens of its adopted biotic community, so much the better for its naturalized status. An example of naturalized species, so understood, provided by Westman (1990) are eucalypts in coastal California. Although ecological restorationists are unlikely to try proactively to establish naturalized species, they may be more tolerant of

them, in their on-going management efforts, than they are of aggressive exotics (Westman 1990).

Ecological restoration is an important component of the "transdiscipline" of conservation biology, the ultimate goal of which is the preservation of biodiversity (Meffe and Carroll 1997). Without an acute sensitivity to considerations of spatial scale, however, management practices clothed in the mantle of biodiversity may be misguided. For some have argued – self-servingly, one suspects – that introducing exotic game species "enhances" the biodiversity of host communities (Tanner *et al* 1980). But this is a specious argument when we consider biodiversity in respect to a hierarchy of spatial scales and levels of biological organization. Clear Lake in California, to take a case in point, had only twelve native fish species; it is now home to twenty-three (Moyle 1989). Thus its fish fauna is nearly twice as diverse as in its historic condition. But the biota of Clear Lake is now compositionally similar to many other aquatic communities, reducing biodiversity at the community level of biological organization. More troubling, five of its native fishes were extirpated as a result of the introduction of exotic fishes, of which two are now globally extinct. According to Noss (1995, p. 35), "the global scale is the most critical scale for evaluating these kinds of changes". Of course, it must be remembered that sometimes the introduction – whether direct or indirect, intentional or unintentional – of particularly invasive or aggressive exotic species can dramatically decrease biodiversity at every scale (Coblenz 1990). A few such introductions are infamous: the unintentional introduction of the sea lamprey and alewife in the upper Great Lakes; the unintentional introduction of the brown tree snake on Guam; the intentional introduction of kudzu to the southeastern United States; and the intentional introduction of the Nile Perch in Lake Victoria.

8. A scalar distinction between pre- and post-industrial human disturbance

The contemporary "flux of nature" paradigm in ecology, however, raises more fundamental and more challenging questions for restorationists in particular and conservationists in general. If human beings have been an ecological force on every continent, except Antarctica, throughout the Holocene; if disturbance, both anthropogenic and nonanthropogenic, has always been frequent, violent, and ubiquitous; and if, as a consequence, the landscape has always been a mosaic of ever-shifting patches, why should we be concerned with ecological restoration at all? The species composition of a given site has always been changing. What's wrong with the way things presently are? As Pickett and Ostfeld (1995, p. 273) note, "For all its scientific intrigue, the flux of nature is a dangerous metaphor. The metaphor and the underlying ecological paradigm may suggest to the thoughtless and greedy that since flux is a fundamental part of the natural world, any human-caused flux is justifiable". I have given reasons why targets selected in reference to the evolutionary time scale are inappropriate for ecological restoration; and I have given reasons why more distant points in the ecological time scale are also inappropriate targets for ecological restoration. But I haven't so far given any reasons why very recent points in the ecological time scale are inappropriate targets for ecological restoration. In Dane County, Wisconsin, for example, why not ecologically restore a retired farm, such as Leopold purchased in 1935, to its condition in the 1920s, rather than to its condition in 1830s (Meine 1988)?

Higgs (1996) hints at a scientifically defensible answer. What he calls "good" ecological restoration should exhibit "functional success". In general, according to Higgs (1996, p. 343), functional success is achieved when "biogeochemical processes" in restored ecosystems "operate normally". In other words, a target criterion for ecological restoration should be a condition that Aldo Leopold (1999b) called "land health" or a condition currently called "ecosystem health" (Costanza *et al* 1992). The examples of biogeochemical processes, which may be normal or abnormal, given by Higgs (1996, p. 343) are "flushing rates, ion exchanges, and decomposition". Leopold (1999b) stressed rates of soil erosion, loss or gain of soil fertility, amplitude of variation in stream flow (the "flashiness" of streams), length of food chains, complexity of food webs, and amplitude of variation in animal population cycles. The biogeochemical processes on unrestored sites affected by urban and suburban development, modern agriculture (especially industrial agriculture), and industrial forestry, unfortunately, do not function normally, that is, they do not manifest land or ecosystem health. Thus, "restoring" a retired farmstead to row crops and continuously grazed pastures would not be appropriate or "good" ecological restoration.

To counter the danger of the flux-of-nature metaphor and the underlying ecological paradigm, Pickett and Ostfeld (1995) identify three general ethical limitations on "human flux" in "the natural world" – physiological, historical, and evolutionary limitations. Industrial human beings challenge organisms with a suite of synthetic molecules that they are not adapted to handle. That's an example of the physiological limitation. A given site may not have the seed bank to respond to a historically unprecedented anthropogenic alteration, such as a strip mine or clear cut. That's an example of the historical limitation. Interrupting historical patterns of gene flow

within populations of species, by isolation, or by artificially providing the opportunity for hybridization are examples of the evolutionary limitation.

Pickett and Ostfeld (1995) provide more general, scalar criteria for assessing anthropogenic changes imposed on nature. They identify "two characteristics of a human-induced flux (that) would suggest that it would be excessive: fast rate and large spatial extent" (Pickett and Ostfeld 1995, p. 274). For example, a bison herd passing over a patch of prairie denudes and tramples the grasses and forbs. The effect might be compared to plowing. But the same prairie patch might not be disturbed by a passing bison herd in the same way for a dozen years or more, while annual plowing would be an example of an anthropogenic disturbance or flux at an excessive rate – that is, of a temporal scale that exceeds the historical limitations of a site. To take another example, windfalls break up the continuity of forests. So do exurban real estate developments. If such patchy anthropogenic clearings were widely scattered in spatial distribution, they would not be ecologically problematic. But if their spatial distribution reduces an otherwise continuous forest to all edge, making it unfit habitat for interior obligates, then exurban real estate development becomes ethically reprehensible.

9. Is ecological restoration hubristic?

Considerations of temporal and spatial scale, therefore, make it possible for us to distinguish between industrial and non-industrial human disturbance in a scientifically justifiable and non-arbitrary way, without invoking an evolutionarily suspect distinction between "man" and nature. Ecological restoration, however, must acknowledge the existence of preindustrial human disturbances and simulate at least some of them in recovery plans. Ecological restoration therefore presupposes on-going site management which might entail such activities as prescribed burns or regulated hunting, in addition to fighting off invasive exotic species. Purists may charge that management is a form of human arrogance and hubris, because it assumes that human beings have more predictive knowledge about the workings of natural systems than can be legitimately claimed (Willers 1992). We should instead put at least a few favoured places back the way they were before we mucked with them, and then leave them alone. Nature knows best. To this complaint I suggest two rejoinders.

First, who is "we"? We human beings or we industrial human beings whose disturbances have been so frequent and widespread that they have exceeded physiological, historical, and evolutionary limitations. Human beings have for a hundred centuries at least been part of terrestrial ecosystems everywhere except Antarctica. Therefore, on-going restoration management should aim not at controlling a landscape, but rather, as just noted, at simulating the well-integrated ecological effects of the ecologically incorporated indigenous *Homo sapiens* – to the extent that we can determine what they were, and to the extent that they did not exceed the ecological limitations specified by Pickett and Ostfeld (1995). And, of course, restoration management should be adaptive, changing both its methods and goals in response to experience (Holling 1978).

Second, one of the elements of ecological restoration most emphasized by restoration theorist William R Jordan (1991) is the spiritual benefits it affords participants. The traditional wilderness idea either excludes people or relegates them to the role of voyeurs, attempting to move through the landscape with minimal effect (Plumwood 1998). The restoration idea provides a more active and meaningful role for human participants as enablers and co-creators (Jordan 1991).

10. Conclusion

Let me sum up what I have tried to convey here. At first blush ecological restoration seems simple and easy in respect to ends, however complex and difficult it may be in respect to means. Ecological restoration should aim to recreate the original condition of a site – that is, the condition of the site at settlement. In what may be the first manifesto of ecological restoration, that is exactly what Aldo Leopold (1999a) said it should be about (Meine 1988).

This simple and easy understanding of the appropriate norm for ecological restoration is premised on two myths that then prevailed – the wilderness myth and the ecological-equilibrium myth. Subsequent changes in cultural geography and ecology have made ecological restoration more problematic than in Leopold's day. *Homo sapiens* has been a ubiquitous and ecologically significant species on all continents except Antarctica throughout the Holocene. And the individualistic flux-of-nature paradigm in ecology has replaced the holistic balance-of-nature paradigm. If nature is but a series of human-influenced, ubiquitously disturbed, ever-changing landscapes, what moment – what snapshot from the past – should we attempt to restore?

Some prominent conservationists have suggested that the norm for ecological restoration in the Western Hemisphere should be the end of the Pleistocene period, because *Homo sapiens* was not a significant species in the Western Hemisphere until the advent of the Holocene. The end of the Pleistocene, that is, is the last time in which the Western Hemisphere was in a perfectly

"natural" condition, a truly wilderness condition. That conclusion presupposes that the appropriate temporal scale for ecological restoration is evolutionary time. I suggest instead that the appropriate temporal scale for ecological restoration is ecological time, defined by the periodicity of ecological disturbances. Correspondingly, the appropriate spatial scale for ecological restoration should also be defined ecologically – in terms of such units as landscapes and bioregions.

Ecological scales are more in accord with conventional intuitions about restoration, which make the condition of an area prior to disturbance and conversion by industrial *Homo sapiens* the target for restoration efforts. They are also useful in coherently distinguishing between native, exotic, and naturalized species. Disturbances wrought by industrial *Homo sapiens* exceed the limitations of ecological temporal and spatial scales. Finally, because *Homo sapiens* were a significant ecological force in the New World throughout the Holocene, to be successful New World ecological restoration must simulate well-incorporated, preColumbian anthropogenic ecological disturbances, principally through prescribed burning and regulated hunting. Such activities provide contemporary people with an opportunity to interact meaningfully and positively with nature.

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