The ongoing extinction event: a deep time, eco-evolutionary perspective for mitigation and reconciliation management

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Abstract

The current accelerated extinction tempo and the attendant decline in speciation rates are expected to segue into a mass-extinction event in the next few centuries. It cannot be stopped and will have profound implications for humans not yet born. What can be done? To begin, it is clear that the customary short-term conservation strategies with their scale mismatches fail to work in the long term, because they ignore the slow variables associated with deep time that ultimately drive the eco-evolutionary dynamics of ecosystems. Also, it is clear that large population ranges not only reduce extinction rates, but also enhance speciation rates. Hence, mitigation strategies for protecting as much evolutionary potential as possible during the forthcoming century and subsequent millennia (10^2–10^4 years) necessitate a focus on nonlinear, self-organizing, eco-evolutionary complexity that emerges from the slow processes embedded across expansive spatial and temporal scales. Management schemes for the effective protection of eco-evolutionary couplings include restoring apex predators, maintaining eco-evolutionary abundances of important species, linking bottom-up and top-down control of food webs, establishing and protecting corridors between ecosystems, strengthening the negative feedbacks that sustain eco-evolutionary interplay, and protecting and restoring biodiversity and biodisparity. Moreover, given that the vast majority of ecosystems worldwide are human dominated, it is imperative that the geographical range of diverse biota be expanded into these anthropogenic habitats, a sharing of living space promoted by reconciliation ecology. To illustrate the theoretical efficacy of the above, we briefly apply

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reconciliation ecology to the long-term eco-evolutionary management of the densely populated northeastern United States.
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1 Introduction

Because extinction rates are currently estimated to be between 100 to 1,000 faster than normal [1], many scientists believe that the Earth is poised precariously at the brink of a mass extinction that likely will materialize in the next few centuries [2, 3]. By the end of the 21st century, terrestrial and marine habitats are liable to lose between 20 and 40% of their extant species [4, 5]. According to Meyer [6], "…the extinction crisis – the race to save the composition, structure and organization of biodiversity as it exists today – is over, and we have lost." Unlike the five mass extinctions since the onset of the Paleozoic Era, the ultimate cause of today's biological devastation is clear-cut: the global collapse of ecosystems is the direct or indirect result of human agency [7, 8]. As stated by Gallagher and Carpenter [9], "…in the wake of scientist's realization…there are no places left on Earth that don't fall under humanity's shadow."Given the intellectual and technical acuity of *Homo sapiens*, can the impending mass extinction be mitigated, such that as much evolutionary potential as possible is preserved for the deep geologic future? In theory, it is possible to do so; in practice, we cannot know unless we try with a moral resoluteness to do our very best. The theoretical aspects of maximizing evolutionary history for posterity are the focus of this article; the complex moral reasons for doing so require a separate paper in a different venue.

2 An eco-evolutionary conservation rationale

Conservationists manipulate the fast ecological variables of ecosystems over the short term in order to protect or enhance biodiversity, and they assume that the slow evolutionary processes are negligible over brief spans of time. Actually, the premise of short-term evolutionary stasis is incorrect, as shown by documented contemporary evolutionary change among numerous species of plants, invertebrates, and vertebrates [10]. The fact that ecological and evolutionary processes occur at similar time scales implies that their feedbacks co-determine the complex dynamics of ecosystems [11] in the short as well as in the long run [12, 13]. As such, understanding the inherent complexity of ecosystems requires an eco-evolutionary perspective, whereby both the ecological effects of evolutionary developments *and* the evolutionary consequences of ecological dynamics are considered [14–18]. As Post and Palkovacs [19] assert, empirical evidence indicates that eco-evolutionary feedback can change the ecological role of organisms and the course of evolution. After all, according to Hendry *et al*. [20], "(c)urrent biodiversity is the product of past evolution, just as future biodiversity will be a product of contemporary evolution." The point of these revelations is obvious: adaptive management schemes for conserving complexity of ecosystems during a time of accelerated extinction require a deep time (10^2–10^4 years), as well as a short term (10^0–10^1 years), evolutionary outlook in order to appraise more effectively the future state of these systems. According to Western [7], the "rate and scale of change in the mosaic of human land uses will have huge and as yet unpredictable consequences for evolution." Besides, ignoring a long-term perspective in conservation limits what we can know and understand about the potential complexity of social-ecological systems that will emerge in the future [21].

Few doubt that the current extinction crisis will have weighty effects on the impending prospects of evolution, which will emerge from the nonlinear, self-organizing interactions of both extinction and speciation rates. The diversity within any biological system is the "…cumulative difference between the creative process of speciation and the destructive process of extinction" [22]. Although the products of evolution are not predictable, "…we can make meaningful estimates about evolutionary *processes* as they will be affected by the depletion of biological diversity" [23]. For example, Erwin [24] explains that "(c)onservation of only an accumulation of mostly nonradiating endemic taxa, the current conservation strategy…, is like saving living fossils, something of human interest, but perhaps not beneficial to the protection of evolutionary processes and environmental systems that will generate future diversity." This perspective underscores a critical oversight of current management practices: the unwillingness to address in a forthright way the real negative, long-term impacts that the combination of the dwindling of habitats for wild species and the debilitating human dominance of ecosystems everywhere will have on the future eco-evolutionary dynamics that promote biodiversity.

3 Adaptive management as if evolution matters

Attempting to assess the circumstances of ecosystems thousands of years into the future is a daunting proposition. Yet, the point is not to predict their state, an impossible task, but instead to restore the eco-evolutionary dynamics of present-day ecosystems as best as possible in order to sustain them for the long term. How does one do this? First, rather than maintaining the *status quo*, the usual objective of preservation strategies, it is prudent to adopt a more dynamic management stance with an eye to nurturing change and diversity in line with a truly evolutionary mindset [25]. What matters with this way of thinking are not objects in space, but processes through time [26]. The point is not to force the system along a pre-determined direction, but to allow it to evolve flexibly, and by so doing enabling it to self-organize and be transformed organically. In essence, it is "important to maintain the ability for organisms to continue to adapt and evolve to new circumstances" [1]. At present, "extinction (is) biased towards certain groups and habitats that are especially vulnerable to people and their activities" [1]. This discord needs to be addressed. Second, it is crucial that the geographical ranges of species be enlarged. This key precept of management is an onerous one because of the human proclivity to modify, occupy, develop, and exploit ecosystems the world over. Yet, it is clear that rates of both speciation and extinction are directly affected by the geographical range sizes of species. Rosenzweig [22] states that "(l)arger ranges tend to increase the speciation rates and decrease the extinction rates of otherwise similar species." At the moment, habitat destruction and fragmentation, which induce species emigration and population extirpation, represent the primary anthropogenic forces that threaten evolutionary processes and truncate the future diversity and, hence, the biological evolution of the Earth [27].

The main point of this argument, if correct, demands that an evolutionary basis be a central tenet for developing conservation efforts that matter over the long term. As noted by Lankau *et al*. [28], "(t)he evolutionary response of populations to human-induced environmental changes will be controlled by a few basic processes, namely the past evolutionary history of the population, the nature of selection imposed by the change, the level of genetic variation present in populations, and finally the connections between populations on a landscape." Consideration of each of these factors can inform policy and management practices for promoting eco-evolutionary processes.

Two points need commentary. First, the values imbedded in the declaration to incorporate evolutionary principles in conservation schemes are important to consider, because opting to embrace a deep-time management perspective is ultimately a moral and not merely a scientific decision. Delegating the responsibility of managing ecosystems over eco-evolutionary time scales to international, federal, state, and local agencies ultimately involves policies determined by political and social discretions and decisions. Second, the management strategies described in the next section, although purported to be directed at preserving evolutionary processes, likewise address the year-to-year conservation efforts designed to protect and restore the ecological dynamics of ecosystems. The two approaches to management – one ecological, the other evolutionary - need not be mutually exclusive; in fact, they are intricately intertwined. Moreover, this eco-evolutionary mindset will provide deeper insight into the multifarious environmental impacts arising from unencumbered, prolonged human agency.

4 Some conservation priorities for mitigating the imminent mass extinction

What follows are synopses of time-tested management strategies that can be employed selectively to minimize extinction rates while supporting evolutionary change, and by so doing enhance the ecological resilience of populations, communities, and ecosystems to adapt to the environmental ravages of anthropogenic forces. Hanski [29] states: "Dispersal and gene flow are key processes…, linking demographic and evolutionary dynamics to each other, facilitating but also constraining the expansion of the current niche and the geographical range of species and determining the spatial scale and pattern of adaptation in heterogeneous environments." It is becoming clear that allowing ample scope for evolutionary processes within ecosystems actually enhances their ecological resilience to environmental assault and degradation [30, 31].

Each of the conservation schemes described below not only helps safeguard the ecological resiliency and diversity of ecosystems, but also protects the eco-evolutionary dynamics while allowing maximal evolutionary potential to propagate into the geologic future. It should be noted that each of the conservation strategies below are not discrete entities; rather many of them overlap and so spill across other critical eco-evolutionary processes. After all, ecosystems are whole, integrated entities, despite our reductive thinking about them. Finally, we note that implementation of these management schemes to ecosystems densely inhabited by people will be difficult; however, this is no reason not to try as people become educated about the seriousness of the impending mass extinction.

4.1 Restoring apex predators

During the past millennia, humans have eradicated apex predators worldwide, because these large animals – wolves, cougars, grizzly bears, polar bears, wolverines, sharks, among others - are dangerous and compete effectively with people for food [32]. Their extermination eliminates the top-down control of food webs, frequently resulting in a mesopredator release that undermines the diversity and trophic complexity of an ecosystem [33, 34]. A mesopredator release is a process whereby mammals (carnivore or herbivore) of intermediate size abound once an apex carnivore is extirpated, which causes negative cascading effects on prey species within the system [35]. The classic example is the eradication of the wolf in the Greater Yellowstone Ecosystem, which allowed the ascendency of coyotes and elk, the latter overgrazing the area, which in turn caused the loss of beavers and songbirds [36]. Reintroduction of the wolf reversed the mesopredator release and the Greater Yellowstone Ecosystem rebounded from its degraded state, regaining ecological complexity, resiliency, and biodiversity. Prugh *et al.* [32] point out that “(t)he ecological release of mesopredators has negatively affected our oceans, rivers, forests, and grasslands, placing added strains on prey species that in many cases are struggling.” However, they warn that the reintroduction of apex predators “will require substantial habitat restoration, greater public acceptance of large, carnivores, and (human) compromises most directly affected by these predators.”

4.2 Maintaining the eco-evolutionary significant abundances of important species

Keystone species, a phrase first used by Paine [37], refers to species that promote astounding biological and habitat diversity that is disproportionate to their abundance. Examples of keystone species include wolves, coyotes, beavers, prairie dogs, alligators, sea otters, and killer whales. The concept with its focus on a single species has made it amenable to conservation strategies: protection or restoration of a keystone species is a clear-cut goal that promotes ecological complexity. Lately, the notion of a keystone species is being criticized, because it ignores the fact that biological systems are incredibly intricate and their complexity depends not simply on keystone species, but also on strongly interacting species [38]. For example, Sala and Graham [39] in an exhaustive review of kelp-forest research concluded that in the order of half of the macroinvertebrate herbivore species are strongly interactive. Although information is sparse generally, some ecologists believe that “a significant proportion of invertebrate and vertebrate are sufficiently interactive to warrant attention if recovery criteria are an issue” [38]. Furthermore, it is crucial that eco-evolutionary significant populations of important species that are not keystone species be protected and restored as well. A case in point is the overfishing of forage fish, which sustain an array of predators, including sea birds, fish, squid, and marine mammals [40, 41]. The implications of such discoveries for mitigating the collapse of ecosystems and abating extinction spasms are crucial for deciding on policy protocol and management practices, because the maintenance of population densities of strongly interactive species and promotion of their maximal spatial distributions appear to be key conservation precepts [42].

4.3 Linking bottom-up and top-down control of food webs

Food webs can be conceived as communities of organisms that process energy and nutrients through trophic interactions, both strong and weak, that cohere into networks of producers and consumers. Bottom-up control refers to the primary plant production that is passed up food webs to animal consumers in contrast to top-down control whereby consumers, such as apex predators and keystone species, regulate producers and so augment the complexity of food webs. Jointly, the two sets of control create guilds, which are similar groups of species fastened together into trophic associations. Energy and matter are fixed by autotrophs and passed up the food web to heterotrophs; negative feedbacks are associated exclusively with top-down control, “from consumers who can regulate the rate of resources issuing from producers” [43, 44]. During the past thousand years, large apex predators, which have a critical influence on the intricacies of food webs, have been systematically extinguished by hunting and fishing, shortening the length of food chains, causing mesopredator releases, and creating trophic skews [45]. “Mesopredators, such as coyotes, snakes, rats, house cats, foxes, and predacious snails, have been released to threaten sensitive prey species such as songbirds, seabirds, endangered mammals, and snails [43].”

4.4 Establishment of corridors

Creating and maintaining corridors between protected areas has a long-standing history in conservation [28, 46]. New analytical tools have been developed to integrate landscape patterns with behavioral processes, creating more effective linkages across landscapes [47, 48]. Such linkages allow gene flow and conserve eco-evolutionary patterns and processes, which are vital for mitigating the extinction loss of species [49]. Climate warming currently underway gives precedence to the establishment of corridors oriented north-south rather than east-west [30]. Landscapes are becoming increasingly fragmented as human populations grow in numbers, technologies become more powerful and accessible, and national and global economies more aggressive in resource exploitation. Both populations of species and their gene flow are being compromised as never before as the rates of environmental despoilment and species extinctions by human agency accelerate. Creating corridors is critical for conservation, restoration, and mitigation; yet, it is becoming increasingly difficult to design and implement such physical connections between isolated populations of organisms, given the expansion of people and their infrastructure across vast tracts of landscape that are no longer even quasi wild. This is where values come into play. Ashley *et al*. [10] write: "As a final point, incorporation of evolutionary thinking into conservation biology raises a possible philosophical contradiction between what it is we ideally hope to conserve and pragmatically what we can actually accomplish."

4.5 Strengthening negative feedback loops

Complex adaptive systems, such as ecosystems, are characterized by nonlinear processes, self-organization, emergence, and internal feedback loops [50]. A negative feedback suppresses change and allows a system to self-regulate [51, 52]. Its antithesis is positive feedback, which accelerates transformation, which can lead to increasing rates of ecological cascades and extinctions. It is paramount that negative feedback when identified be maintained and even strengthened. Protection and reintroduction of apex predators as well as safeguarding strong interactive species, both of which produce diversity and complexity, depend on the robustness of negative feedback loops. In addition, many ecosystems and habitats have self-regulating capacities due to feedback loops. For example, salt marshes can adapt to a rise of sea level by promoting mud deposition due to the baffling effect of the plants as tidewater floods in and ebbs out with its load of suspended sediment, or the marsh itself can migrate landward with the rising seas. However, if dams reduce or eliminate the supply of mud to the nearshore or if a seawall prevents the marsh plants from migrating onshore, the plants will succumb and die in short order as sea level rises. In turn, the organic detritus that is normally exported from the marsh and which sustains the detritus food webs of estuaries and the adjoining shelf will be impacted as well. So, the negative feedbacks of salt marshes that allow them to endure a rise of sea level require that humans not interfere with the system's sources of mud and that seawalls be dismantled.

4.6 Maintaining biodiversity and biodisparity

The resources for conservation efforts are finite and inadequate. As such, the allocation of funds and personnel mostly for the protection of endangered species is mistaken, because these efforts will not reduce the extinction rate in the long term [53]. Rather, in order to maximize preservation, the limited resources should be used to protect biodiversity in a cost-efficient manner [53]. Though progress to do so is apparent, biodiversity continues to decline at an alarming, ever-increasing rate [54]. A conservation focus on diversity, whether the term is a proxy for species abundance, gene variation, or adaptive behavior, will track to some degree changes in the state of evolutionary processes, which in turn will have long-term consequences on the ecological viability of populations, communities, and ecosystems [55]. According to Myers and Knoll [23], declines in biodisparity, an indicator of "a biota's morphological and physiological variety," are crucial to assess as well as biodiversity. In fact, the culling of species-poor genera during the past 2,000 years has degraded biodisparity at rates far greater than the loss of species themselves [56], which implies that this is a loss of a specific eco-evolutionary potential that cannot be regained.

5 Conservation implications of eco-evolutionary dynamics

It is obvious that eco-evolutionary dynamics and biodiversity of ecosystems everywhere will be fundamentally altered as extinction rates increase and speciation rates decrease because of anthropogenic forcing. As Cardinale *et al*. [57] posit, "(t)he impact of biodiversity on any single process is nonlinear and saturating, such that change accelerates as biodiversity loss increases." The long-term trend is clear: there will be severe extinction cascades by the end of the 21st century that will undermine the eco-evolutionary functioning of ecosystems everywhere (58). As everyone recognizes, offsetting this trend requires a deep-seated change in the attitudes and habits of humans, a fundamental makeover that regrettably is not likely to happen any time soon. Therefore, given these expectations, it is imperative both practically and ethically that conservation efforts be directed at mitigating the loss of the Earth's biodiversity and its evolutionary potential [59]. However, given our lack of understanding of eco-evolutionary dynamics generally and specifically, how can we make informed conservation plans and design effective management policies for curtailing the loss of the planet's biota over the long term?

It seems to us that we need to conceptualize the biodiversity problem with a broad-brush approach and consider management priorities. The proximate causes that are rapidly undermining the eco-evolutionary processes and the biodiversity of ecosystems are well known; they include habitat destruction and fragmentation, invasive species, climate change, overharvesting, and environmental toxicity, among others [2]. Collectively the consequences of these anthropogenic drivers are clear for the foreseeable future: extinction rates will increase and speciation rates will decrease, both at accelerating rates [23]. "Action taken over the next few decades will determine how impoverished the biosphere will be in 1,000 years when many species will suffer reduced evolvability and require interventionist genetic and ecological management [60]." Hence, conservation measures should be directed at reducing extinction while promoting speciation over the long term. Given that many ecologists and evolutionary biologists concur that large populations of organisms stretched across an expansive area tend to be correlated with low extinction rates and high speciation rates [22], conservation measures over the next millennia need to be applied across landscapes, *incorporating the landscape patterns modified by humans* [61]. Furthermore, data, though limited, suggest that the effects of diversity become stronger as spatial scales increase [62–64]. So, it stands to reason that expanding, connecting, and restoring habitats are essential conservation strategies for protecting diversity of ecosystems, as well as conserving their eco-evolutionary interactions. In essence, rather than trying to “manage” species and eco-evolutionary dynamics directly, one strives to create the physical and biological conditions that will allow social-ecological systems to self-organize and evolve to the ever-changing conditions of the landscapes patterns they occupy [65], including the human-built landscapes [61]. As a final point, it has become clear that intra-specific genetic variations are crucial for promoting evolutionary resilient landscapes [66, 67]. “Loss of genetic diversity within populations can be associated with inbreeding depression, which in turn results in lowered fitness and increased risk of extinction [68].” As such, genetically distinct populations are a critical aspect of biodiversity and such unique populations need to be protected from extirpation in an effort to salvage the Earth’s future evolutionary prospects.

The six management strategies described briefly in the preceding section can be applied to achieve the broad goals of enlarging areas being managed while sustaining biodiversity and its eco-evolutionary processes. But to do so, conservationists must adapt a reconciliation perspective to managing ecosystems. Carroll [69], for example, advocates that rather than eradicate invasive species, conservationists assume a conciliatory approach whereby non-native species are used “to address many practical needs including slowing rates of resistance evolution, promoting evolution of indigenous biological control, cultivating replacement services and novel functions, and managing native-nonnative coevolution.” Reconciliation ecology strives to convince people who occupy land adjacent to protected habitats to share their environment with organisms, thereby allowing populations to disperse from refuges into broader, heterogeneous human-modified landscapes [62]. These are admittedly ambitious goals, and yet not to try with vigorous commitment to apply these conservation practices now will without doubt have grave consequences for the biodiversity and biodisparity of the future. Delays at acting now until we “know more” are irresponsible. “Despite the high uncertainty associated with future climate predictions, urgent decisions and rapid action are required to conserve biodiversity, including the genetic diversity that is needed for evolutionary adaption [70]. “Although academic conservation biology still has an important role to play in developing technical tools and knowledge, success at this juncture hinges more on a massive mobilization of effort to do things that have traditionally been outside the scope of the discipline [71].”

6 Applying long-term, eco-evolutionary management to New England, US

We provide a brief overview about how managers might think about conserving the eco-evolutionary dynamics of the northeastern US for the next few millennia. This deep-time approach focuses on protecting and enhancing biodiversity and biodisparity in such a way that it minimizes the anthropogenic impacts on the evolutionary potential of the region. In this mindset, the management goal is not directed at achieving a preferred ecosystem state; rather, the aim is to safeguard short- and long term eco-evolutionary dynamics, and by so doing allow wildlife to adapt to and self-organize into radically changed environments. This means that what emerges in the long run is a function of complex, eco-evolutionary interactions rather than a human-desired state of ecological organization.

6.1 Cultural history matters

During the last four centuries, land-use and resource exploitation by humans have been intense in New England [72]. Widespread deforestation and farming during the 17th and 18th centuries decreased the forest-interior species and enlarged open-habitat species. The converse ecological impacts epitomized the 19th and 20th centuries, as farmland was abandoned and forest area increased [73]. As a consequence, populations of open-field species, such as bobolinks, grasshopper sparrows, and meadowlarks, plummeted while forest-based species, such as white-tailed deer, beaver, moose, and black bear, rebounded [72]. "Therefore,…the assemblage of animals on the New England landscape includes diverse species, each of which is on a different ecological trajectory in response to past and ongoing changes: some are increasing, some declining, others are exhibiting few changes [74]." This implies that this heavily forested and densely-human-populated landscape harbors novel wildlife populations that are in a dynamic stage of chaotic self-organization due to rapid human-induced changes in land cover. Remarkably, despite the rapid environmental changes in New England during the last 400 years, only a handful of species were driven to extinction [74–76]. Why is that? According to Pimm and Jenkins [77], "(s)imply, that there were so few extinctions – and so few species at risk – is largely a consequence of there being so few species with small ranges." Species that are rare have small ranges and are the candidates for extinction.

6.2 Eco-evolutionary conservation: a beginning

The 21st century will be characterized by accelerated habitat despoilment and fragmentation as the human population and their economies continue to grow. Unfortunately, extinction rates worldwide will be magnified by these effects, particularly given the onset of global warming [78–81]. The outcomes in New England likely will include warmer summers and shorter winters, alterations of precipitation and snowmelt patterns, and transformations in the timing of seasonal events [82–84]. The broad consequences of habitat destruction and climate change seem clear [83, 85–88]: species will relocate when possible, some will be extirpated, new species will appear, invasive species will persist and some of those will expand, and contingencies, both small and large, will transpire [89]. Similar ecological dislocations are predicted for the shoreline and the continental shelf that abut New England [90–93]. How the different ecosystems and landscapes of New England will self-organize over time is unpredictable, particularly given the persistent eco-evolutionary flux (far from equilibrium) of the region's biota during the last two centuries.

Anticipating specific eco-evolutionary changes is impossible. To us, it seems that the most obvious management strategy for dealing with this uncertainty is to expand the ranges of terrestrial and aquatic species so that they can adapt and avoid extinction, allowing the most biodiversity and co-evolutionary potential to survive into the deep future. Instead of focusing on protecting selected species, it seems prudent to devote funds and effort at expanding and connecting wildlife habitats wherever possible. Creating biological corridors can provide plants and animals pathways to under-populated and higher quality habitats [94]. When effective, corridors can reverse the trend towards diminished genetic and demographic conditions and thereby reduce the peril of extinction while protecting, perhaps enhancing, the biodiversity of the region [95, 96]. Although the efficacy of wildlife corridors to promote dispersion of plants and animals is a contentious issue [97, 98], there are many recent empirical studies that indicate they can be effective dispersal paths for species between isolated habitats [99–103]. Alternatively, the modeling results of Falcy and Estades [104] "indicate that, for a given amount of habitat, patch enlargement can increase population size more than the establishment of biological corridors." It appears that both the establishment of corridors and the enlargement of habitat patches need to be assessed at a particular site before deciding which is best to implement for upgrading its biodiversity and associated eco-evolutionary processes. Finally, "(c)onnecting isolated forest fragments by reforesting them in areas rich in small-ranged species is an effective and cheap way of preventing extinction [77]."

Equally important is the reintroduction of apex predators to New England's landscapes and seascapes, because their catastrophic declines have caused mesopredator outbreaks that "often lead to declining prey populations, sometimes destabilizing communities and driving local extinctions [32]." Candidates for reintroduction include gray wolves, black bears (already present), cougars, mountain lions, wolverines, and numerous species of sharks [105]. It should be noted that some of these, such as the wolf and sharks, are keystone species as well. Although efforts to protect large apex predators are costly and require large territories, "…these financial costs may well be offset by the benefits of reduced mesopredator abundance and greater ecosystem resiliency [32]."

Because the areal expansion of habitat patches, the creation of corridors, and the reintroduction of apex predators will reduce the risk of extinction, the combination of strategies, over the long term, will help link up bottom-up and top-down control of emerging food webs, will strengthen negative feedbacks, will encourage the emergence of strongly interactive species, and will promote both biodiversity and biodisparity. Once these self-organized biological processes are recognized, they can be protected with an eye at mitigating the eco-evolutionary dynamics of the ever-changing ecosystems and landscapes of New England.

6.3 Reconciliation ecology and education

New England has a long history of human development and environmental impact [106]. Much of the region has moderate to high densities of human settlement, which has severed the diverse landscape into a patchwork mosaic, referred to by some as novel ecosystems [107, 108]. "Rather than insist on protecting habitat from human use, reconciliation ecology works in and with the human dominated habitats….(and) gives us the realistic hope that we can prevent most losses of species [109]." Given the paucity of "natural" reserves, we must expand habitat patches into and construct wildlife corridors across cultural landscapes (110). In other words, the human-interfaced land is to be shared with wildlife. There is no other way to enlarge habitat patches and connect them with a network of corridors without participation from the region's landowners and citizenry. Arendt [111] maintains that "(w)hen local officials and residents are sensitized to the kind of "wall-to-wall" development that their existing conventional land-use codes will ultimately produce, they often become much more amenable to revising those codes to *require* that basic conservation principles from the field of landscape architecture be combined with zoning ordinances produced by land-use planners to fashion an improved process for designing new subdivisions, in which the protected greenspace is laid out to create an interconnected network of conservation lands, thus attaining the goal of "linked landscapes."" He continues: "The advantage of this approach (creating greenway corridors) lie in its economy, administrative ease, fairness to landowners, and political acceptance, which combine to make it potentially one of the most promising physical planning techniques to emerge in recent decades [111]." Reconciliation ecology provides a means for transforming human-dominated landscapes into "environment(s) more suitable for native biodiversity, and/or assisted dispersal to allow suitable native organisms to reach appropriate sites within artificial ecosystems [110]."

The acceptance and application of eco-evolutionary-enlightened management is not in the purview of academic conservation ecology, because the "remaining challenges are largely social, political, economic [55]" and, we add ethical. What is desperately needed is a colossal effort to educate citizens, business people, policy makers, and politicians about the moral efficacy of a vision of a world that is populated by diverse, abundant species for people not yet born. A group of geologists, ecologists, and philosophers continues to work on these urgent issues with the financial support of Colgate University's Boyce Funds and the Picker Interdisciplinary Science Institute. Clearly, the time to examine and respond to local, regional, and global disruptions of eco-evolutionary processes is limited. We may have only a few decades [60] to decide to manage with a deep-time, eco-evolutionary perspective, if we are to avert a massive kill-off of the Earth's magnificent biota, a legacy that will be incomprehensible to future generations of *Homo sapiens*.

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