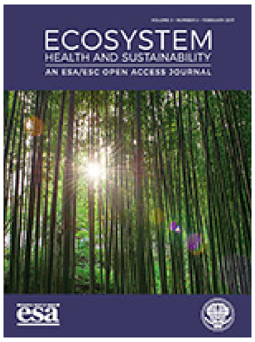

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A portfolio approach to managing ecological risks of global change

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Abstract. The stressors of global environmental change make it impossible over the long term for natural systems to maintain their historical composition. Conservation's new objective must be to maintain the building blocks of future systems (e.g., species, genes, soil types, and landforms) as they continuously rearrange. Because of the certainty of change, some biologists and managers question continued use of retrospective conservation strategies (e.g., reserves and restoration) informed by the historical range of variability. Prospective strategies that manage toward anticipated conditions have joined the conservation toolbox alongside retrospective conservation. We argue that high uncertainty around the rates and trajectories of climate and ecological change dictate the need to spread ecological risk using prospective and retrospective strategies across conservation networks in a systematic and adaptively managed approach. We term this a portfolio approach drawing comparisons to financial portfolio risk management as a means to maximize conservation benefit and learning. As with a financial portfolio, the portfolio approach requires that management allocations receive minimum temporal commitments to realize longer-term benefits. Our approach requires segregation of the strategies into three landscape zones to avoid counterproductive interactions. The zones will be managed to (1) observe change, (2) resist change, and (3) facilitate change. We offer guidelines for zone allocation based on ecological integrity. All zones should follow principles of conservation design traditionally applied to reserves. Comparable to financial portfolios, zone performance is monitored to facilitate learning and potential reallocation for long-term net minimization of risk to the building blocks of future ecosystems.

Key words: *adaptive management; biodiversity; connectivity; global change; gradients; portfolio; reserve; restoration; risk spreading; transformation.*

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Introduction

For most of its history, conservation has been based on an assumption that native ecosystem diversity and productivity could be sustained without intervention, allowing natural resource managers to focus on activities that enhance the delivery of favored outputs, including timber, game, and recreational activities. If those management activities began to impair ecosystem diversity and productivity, managers believed they could be reversed by reducing the intensity of management and/or establishing wilderness reserves where native species could thrive (This does not apply to transformatively destructive activities like hardrock mining). Over time, recognition of ecosystems' dependence on dynamic disturbance processes led some managers to seek a historical range of variability, whereby sustainability could be assumed as long as dynamics remained within the historical disturbance regime (Aplet and Keeton 1999). This was all possible because a relatively stable climate resulted in relatively stable and predictable biomes, ecosystems, and communities that fluctuated within bounded conditions. Under this relative stability, past composition, structure, and function of ecological systems could be assumed to last indefinitely, a condition that has been called stationarity (Milly et al. 2008).

Under assumed stationarity, natural resource managers have also sought to identify minimum necessary habitat target values for maintenance or restoration of conditions within the historical range of variability. This type of retrospective conservation planning and management has been an important response to habitat loss and degradation (Magness et al. 2011). Maintenance, recovery, or restoration of particular habitat and landscape attributes (e.g., habitat representation, habitat area, ecological connectivity, species diversity) has guided the establishment and management of conservation networks. Management of these networks has typically been minimal, as in ecological reserves, or entailed one-time interventions intended to restore self-regulation

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under assumed stationarity (see Sydoriak et al. 2000, Franklin and Aplet 2002).

While the establishment of reserves and the maintenance of disturbance regimes within them were important advances in conservation, the prospect of global change, entailing climate change and other relatively recently realized global impacts of species invasions, atmospheric deposition, and land-use transformation, now threatens the future productivity and diversity of ecosystems and the goods and services we expect from them. As Milly et al. (2008) proclaimed, "stationarity is dead," and the sustainability and future productivity of ecosystems is certain to change. New approaches to management are needed that can accommodate the uncertainty and new conditions that are coming. These new approaches must include forward thinking prospective management that anticipates and even facilitates change, but not to the exclusion of retrospective strategies (Magness et al. 2011).

Unfortunately, high uncertainty regarding future climate, ecological conditions, and management consequences makes it impossible to know what strategy to apply, where to apply it, or for what duration to sustain ecosystem diversity and productivity. In this paper, we present an approach to wildland (i.e., land not dominated by urban or agricultural development, whether publicly or privately owned) management in the face of climate change that embraces uncertainty and spreads the ecological risks from global change and the unintended consequences of management among a portfolio of conservation strategies. In the following sections, we review in greater depth how conservation objectives and strategies founded upon stationarity must be replaced by the management of risk to nature's building blocks, the genes, species, and abiotic structures of future ecosystems. We argue that management of risk to these building blocks will require a coordinated application of retrospective (ecological reserve and restoration) and prospective (facilitation of change) management strategies across landscapes. We examine principles of economic portfolio theory as a foundation for instituting a risk management approach to conservation that employs a structured mix of observation, restoration, and facilitation. Rather than insisting on a strict prescriptive approach, we hope to offer a philosophical and adaptive framework using all three management classes for net landscape management of risk, avoidance of counterproductive maladaptation, and the potential to learn.

Ecological Risk from Climate Change: Losing the Building Blocks of the Future

General circulation and downscaled climate models and models of future bioclimatic envelopes predict large-scale and widespread dramatic changes to climate, ecological communities, and ecosystems. Mechanisms of anthropogenic global change include climate-driven extinctions of populations and species, increases in invasive and exotic species, ongoing habitat loss and fragmentation, altered fire regimes, increased insect and disease outbreaks, increased frequency and intensity of drought and storms, decreased snow cover, altered phenologies of tightly linked species, range shifts, and the break-up of long-established plant and animal communities (Parmesan and Yohe 2003, Thomas et al. 2004, Geyer et al. 2011, Hansen and Hoffman 2011, Cameron 2012, Hannah 2012). While it is certain that future communities and ecosystems will be different, it is unknown precisely what that future holds. The paleoecological record demonstrates that populations and species have responded and adapted to slow, historical climate change individually rather than as entire communities, ecosystems, or biomes (Williams and Jackson 2007).

The impact of climate change has been evident for years. Parmesan and Yohe (2003) performed meta-analyses involving over 1,700 species of vertebrate, invertebrate, and plant taxa from temperate, tropical, marine, montane, forest, and grassland ecosystems and found that more than half the species have shifted their ranges along gradients of latitude and elevation or adjusted their phenologies over the last 20–140 yr in response to climate change. These changes are likely due to phenotypic plasticities of behavior, physiology, and morphology, as well as adaptive evolution itself, as was documented for two species of finch in the Galapagos Islands (see review in Grant and Grant 2008). The options for species under these conditions, as aptly described by Hill (2013), are to "adapt, move, or die." These options are consistent with the responses to past episodes of climate change evident in the paleoecological record (see reviews in Schneider and Root 2002, Hewitt and Nichols 2005, Huntley 2005, Lovejoy and Hannah 2005, Hansen and Hoffman 2011, Chester et al. 2012, Clyde and LeCain 2012).

In addition to these direct effects on species, some physical building blocks, such as soils, stream channels, glaciers, and coastal barrier dunes, are similarly threatened by climate change, especially extreme weather events. Geyer et al. (2011) review stressors on biological diversity caused by climate change and include such abiotic effects as changes in physical and chemical soil composition, alterations of surface structure and terrain, sea level rise and coastal flooding, and changes in river and wetland flow and runoff, showing that the loss of these abiotic features can feed back to affect biological building blocks, too.

Regardless of what the ecosystems of the future look like, they are certain to be assembled or derived from components that exist today. Today's genes, populations, and species are irreplaceable legacies of evolutionary time (see review in Huntley 2005, Overpeck et al. 2005, Galbreath et al. 2009, Hellman and Pfrender 2011, Barnosky et al. 2012, Hellman et al. 2012) that are threatened with the highest extinction rates of the last several million years (Thomas et al. 2004, Cameron 2012, see review in Hannah 2012). These legacies of the past represent the invaluable ecosystem capital of the future and are what is at greatest risk from climate change. Physical building blocks too, including soils, stream channels, wetland basins, landforms, and land facets (Hunter et al. 1988, Anderson and Ferree 2010, Beier and Brost 2010), also represent legacies of evolutionary and geologic time that would take eons to replace if lost. The existence of diverse, productive, future ecosystems depends upon conserving these building blocks through an era of rapid change.

Adaptation Options and the Perception of Risk from Unintended Consequences

To address the risk of loss, various authors have put forward numerous adaptation strategies. Obviously, the safest and most comprehensive solution is to reduce the emissions that drive climate change, although that will not address the significant and unavoidable ecological change already set in motion. Beyond that option, the most direct way to reduce risk is to address the stressors in addition to climate change that make species and ecosystems vulnerable to climate change and that present barriers to adaptation. Reducing these anthropogenic stressors has been called the "low-hanging fruit" of climate change adaptation (NCSE 2009) and includes increasing the size and number of protected reserves, restoring altered disturbance regimes, halting and repairing the loss and fragmentation of habitat, managing invasive species, cleaning up air and water pollution, and addressing the legacy of past management. Steps that can be taken to reduce anthropogenic vulnerability include protecting mature and old-growth forest, which has become rare, and halting the conversion of native forest to plantations, which has become too common (Noss 2001, Biringer 2003, Glick et al. 2009). According to Galatowitsch et al. (2009), "Key resilience actions include providing buffers for small reserves, expanding reserves that lack adequate environmental heterogeneity, prioritizing protection of likely climate refuges, and managing forests for multi-species and multi-aged stands."

In addition to reducing the stressors that make species susceptible to changes in their environment, actions can be taken to enhance the capacity of species and ecosystem elements to remain viable in the face of change. Some of these actions have been conceived strictly in the context of climate change, while others have their origins in traditional conservation planning yet remain relevant under non-stationarity. Enhancing adaptive capacity consists of actions to facilitate or improve the ability of species (usually) to respond favorably to change. Among the strategies that have been proposed to increase adaptive capacity to climate change are the promotion of landscape connectivity to facilitate movement; assisted migration when species cannot move themselves; promotion of communities of diverse species, species with diverse genetics, and populations with diverse age structure; and enhancement of seed banks and ex situ conservation.

Each of these strategies involves differing degrees of intervention and carries with it its own risks. Box 1 shows how a sampling of climate adaptation strategies can be organized along a gradient of perceived risk from practices that are generally considered benign, such as monitoring, to practices, like assisted migration, that have elicited vigorous protest due to their perceived high level of risk (Hunter 2007, McLachlan et al. 2007, Heller and Zavaleta 2009). This list is not meant to be exhaustive, nor is it essential that the ordering of risk is precisely correct. The point is that not all strategies carry the same amount of risk and that risk tolerance affects the willingness of managers and the public to adopt different strategies. The most interventionist options are perceived as the riskiest and also provoke the most objections. It bears noting here that the uncertainty of the future also confers a risk of inaction, whereby inaction is not necessarily the least risky action; however, public perception of risk seems to increase with the intrusiveness of intervention (Heller and Zavaleta 2009).

Spreading Climate Risk Across a Portfolio of Management Risk Classes

In addition to risks associated with the unintended consequences of intervention, future building blocks face uncertain loss (i.e., risk) from unknown degrees of climate change and from ecological responses to those changes. In recognition of the risks associated with climate change and its management, scientists are increasingly turning to concepts of risk management as the focus of climate change adaptation and mitigation strategies (IPCC 2014, Painter 2015). The IPCC Fifth Assessment Report (IPCC 2014) breaks risk down into its components of vulnerability, exposure, and hazard and advocates measures to reduce each. Another approach to risk management is to spread ecological risk among a variety of strategies. Millar et al. (2007), Lindenmayer and Hunter (2010), and Dawson et al. (2011) identify the need to spread ecological risk as a general guiding concept for the development of strategies. Millar et al. (2007) discuss the need for approaches that variously maintain the historical range of variability, restore the historical range of variability, or speed transformation to new states as part of a risk management approach. Aplet and Cole (2010) affirmed the notion that "stationarity is dead" and suggested that in an uncertain, climate-altered future, there are really only three alternatives: We can *accept change* by releasing ecosystems from human control, understanding that they may evolve into new and different forms; we can *resist change* by investing human

Box 1. A Sampling of Climate Adaptation Strategies Derived from the Burgeoning Literature of Adaptation Options Arranged Top to Bottom in order of Increasing Risk of Unintended Management Consequences

Reduce emissions of climate-altering gases
Monitor ecosystem response to climate change
Reduce non-climate stressors
Enhance habitat area and reduce fragmentation
Enhance diversity and redundancy of ecological reserves
Protect and restore connectivity across climate-relevant gradients of elevation and latitude
Reestablish extirpated native species
Supplement resources (e.g., water, nutrients, food) during extreme conditions
Control invasive species
Maintain genetic banks for later introduction
Irrigate water-stressed sites
Translocate species to new sites
Construct dams and other structures to control hydrology
Create neo-native communities that the paleoecological records suggest grew on the site when the past climate was more like the future will be
Create wholly new ecological communities or large-scale gardening

Notes: The box was derived from Noss 2001, Millar et al. 2007, Joyce et al. 2008, Glick et al. 2009, Running and Mills 2009, Cole et al. 2010, Stein et al. 2014; see also Heller and Zavaleta 2009).

energy to attempt to maintain historical composition, structure, and function; or we can *guide change* by intentionally transforming ecosystems into a novel condition that we hope will be more resilient to further change or that will support ecosystem components or services that have been lost from other wildland ecosystems (Aplet and Cole 2010).

The three management trajectories are rooted in a conceptual model of wildland character discussed by Aplet (1999) whereby the nature of any landscape can be described in terms of its ecological condition and its degree of human control. The model represents all lands as existing in the space created by two axes, one describing ecological condition along a gradient from novel to "pristine" (i.e., intact with respect to its historical composition, structure, and function) and the other defined by the degree of intentional manipulation from controlled to "self-willed" (Fig. 1). (For some people, "pristine" conveys notions of freedom and untouched nature that are not intended here and might better be replaced with "historical," "primeval," or "intact," but it is the word used by Aplet (1999) and so appears here.) The axis reflects ecological novelty in the sense of Radeloff et al. (2015) as "the degree of dissimilarity of a system, measured in one or more dimensions relative to a reference baseline, usually defined as either the present or a time window in the past." In the upper right corner of this space occur the most uncontrolled, unaltered places—the large, ecologically intact landscapes where historical conditions have been maintained without much human intervention. The Arctic National Wildlife Refuge is a prime example. Its antipode, the highly altered, highly controlled environment of the city, occurs in the lower left corner. Still other landscapes, such as the historically accurate (at least in terms of the plant community) but highly manipulated prairie restoration project at the University of Wisconsin Arboretum, belong in the lower right-hand corner, and the C&O Canal, an artificially constructed waterway parallel to the Potomac River, overgrown with exotic species, might reasonably be called highly altered or novel, yet untrammeled and self-willed, as it is largely left alone by managers (though it is no doubt influenced by the condition of its surroundings). Recognizing that the four corners of this diagram represent mythical ideals and that no place is completely trammeled or untrammeled, natural or novel, landscapes can be described as

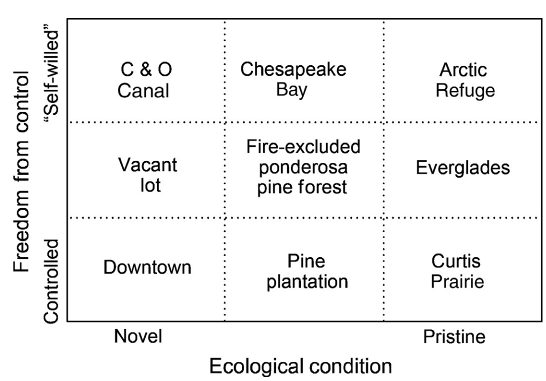

Fig. 1. Any landscape can be represented in the two-dimensional space created by ecological condition and freedom from human control. Note that, in this case, "pristine" refers not to an untrammeled state, but to the composition and structure of intact native ecosystems (adapted from Aplet and Cole 2010).

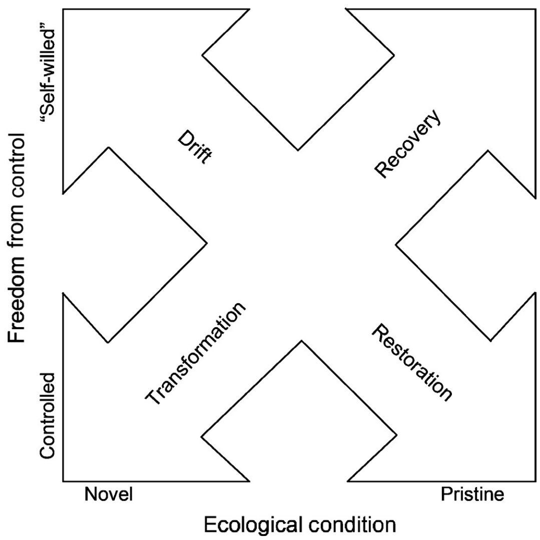

Fig. 2. The same axes that describe land describe the "direction" of management options (adapted from Aplet and Cole 2010).

expressing any combination of human control and historical fidelity.

This two-dimensional conceptualization can be used to contemplate the role of human agency in shaping landscape character (Fig. 2). Increased human effort can drive systems away from pristine conditions through *transformation*, as has typified the progress of civilization. Alternatively, human effort can be exerted to increase historical fidelity and mitigate human impacts through the process of *restoration*. In the absence of active management, land freed from human control can either *recover* toward the pristine or *drift* toward a more novel condition. Franklin and Aplet (2002) assert that, for wilderness, recovery is always the ideal trajectory; however, they recognize that there will be cases in which return to a pristine state is impossible without active restoration. In these cases, the decision to intervene in wilderness "will hinge on whether the potential for [subsequent recovery] outweighs the ecological uncertainties and the magnitude and duration of the required trammeling" (Franklin and Aplet 2002:278).

Having explored these four potential directions of management (recovery, drift, transformation, and restoration), Aplet and Cole (2010) consider the implications of global change for the future of each and conclude that factors such as climate change, species invasions, and atmospheric pollution are so pervasive and powerful that it is unrealistic to expect a particular place to recover to historical conditions if freed from human control over the long term. The ideal of wilderness management, the perpetuation of whole historical ecosystems through passive untrammeling, is no longer tenable in the long run and drops out of the figure in the face of such pressure (Figure 3). Of course, it is important to note that recovery (passive restoration or movement in the direction of historical conditions) will not disappear completely as a process. Where conditions are badly degraded, removal of stressors alone may result in improvement of ecological conditions (e.g., regrowth and succession of cutover or agricultural land, relief from overgrazing, dam removal). When such recovery results in a system that is more resistant to change or resilient to disturbance, recovery can be an important short-term strategy.

Over the long term, however, global change can be expected to drive untrammeled ecosystems away from historical conditions. The only management options remaining for the extended future derive from the three management trajectories described by Aplet and Cole (2010): (1) to *accept change* through the practice of *observation*, (2) to *resist change* through active *restoration*, and (3) to *guide change* through active *facilitation* (Fig. 3). Hybrids of these adaptation strategies may also occur, such as restoring a degraded system to high integrity and then allowing it to change or anticipating climate change and seeking to guide an ecosystem into a condition that occurred historically somewhere else on the landscape. Accepting change may also result in the migration of an historical ecosystem into a new location, though this possibility must be considered unlikely, as paleoecological evidence suggests that ecosystem members (i.e., species) rarely, if ever, migrate together in response to climate change (Williams and Jackson 2007). As mentioned, severely degraded systems may also improve in condition in response to untrammeling from local stressors, even in the presence of global change.

These three management options (observation, restoration, and facilitation), derived from the trajectories suggested by Aplet and Cole (2010), encompass many of the climate adaptation strategies that have been described in the literature for their abilities to minimize vulnerability and exposure to the stresses of climate change. For

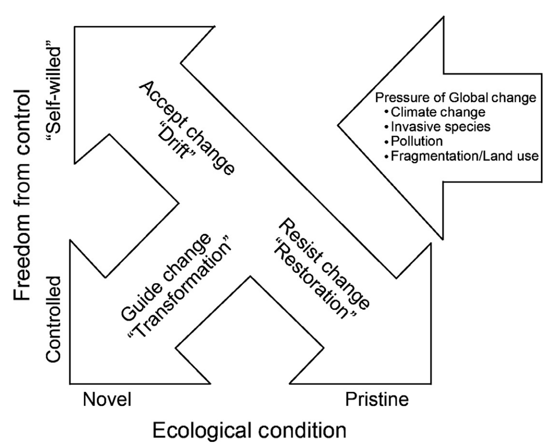

Fig. 3. Global change can be thought of as a pressure on ecosystems driving them away from historical conditions. In the future, degraded sites cannot be expected to "recover" to their historical condition in the absence of human influence (though some short-term recovery is possible upon relief from existing stressors) (adapted from Aplet and Cole 2010).

Box 2. Causes of Maladaptation from Management Undertaken to Promote Resilience to Climate Change (from Noble et al. 2014)

Failure to anticipate future climates
Engineered defenses that preclude alternative approaches
Adaptation actions not taking wider impacts into account
Awaiting more information, or not doing so, and eventually acting either too early or too late
Forgoing longer-term benefits in favor of immediate adaptive actions; depletion of natural capital leading to greater vulnerability
Locking into a path dependence, making path correction difficult and often too late
Unavoidable ex post maladaptation, for example, expanding irrigation that eventually has to be replaced in the distant future
Moral hazard, that is, encouraging inappropriate risk taking based, for example, on insurance, social security net, or aid backup
Adopting actions that ignore local relationships, traditions, traditional knowledge, or property rights, leading to eventual failure
Adopting actions that favor directly or indirectly one group over others leading to breakdown and possibly conflict
Retaining traditional responses that are no longer appropriate
Migration may be adaptive or maladaptive or both depending on context and the individuals involved

example, strategies of reserve establishment, protection of old growth and corridors, allowing natural fire, and monitoring align well with the option to observe change. Using prescribed fire, reestablishing flood regimes through controlled releases, and reconnecting flood plains are familiar restoration actions, whereas more aggressive activities, such as assisted migration and the establishment of "neo-native forests," (Millar et al. 2007) fit in the vein of facilitation. Some are well-established, traditional conservation methods that were successful in the past and are likely to continue to perform well in the future. Others entail significant risk in the context of current conditions or simply due to the lack of a track record, but may nevertheless be worth testing (Lawler et al. 2010).

The IPCC (2007) concluded, "A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change," a judgment echoed by Millar et al. (2007), who stated, "Managing in the face of uncertainty will require a portfolio of approaches, including short-term and long-term strategies, that focus on enhancing ecosystem resistance and resilience…as climates and environments continue to shift." Hobbs et al. (2011) proposed a new "Intervention Ecology" designed around when, how, where, and whether to intervene that echoes the need for a portfolio of approaches that includes active management and simple observation. Similar to Aplet and Cole (2010), Heller and Hobbs (2014) advocate for conservation objectives derived from the past, present, and future, and Stephenson and Millar (2012) suggest four general categories of management action in response to climate change that they call the "4 Rs": *restraint* (leaving some places alone), *resilience* (enhancing an ecosystem's ability to absorb impacts without changing character), *resistance* (actively opposing change), and *realignment* (actively facilitating change). Magness et al. (2011) and Watson et al. (2013) present a similar set of options based on adaptive capacity and exposure. These approaches share with ours the common assertion that managers will need to try different approaches in different places, some with an emphasis on restoration, some on transformative activities, and some involving places we simply leave alone and observe.

Allocating Land Within a Risk Management Portfolio Approach

Categorizing adaptation strategies into three basic classes not only provides a framework for organizing the burgeoning array of options, it also can help guard against willy-nilly application of strategies that may result in *maladaptation*, or "actions or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future" (Noble et al. 2014). The IPCC (2014) reached high agreement with the statement, "Poor planning, overemphasizing short-term outcomes, or failing to sufficiently anticipate consequences can result in maladaptation," and they offered a table of types of maladaptive actions (Box 2). Two themes running through this list are the idea of mistakes made due to imperfect information and the idea that one adaptation action may confound or undermine the success of another. Indeed, the IPCC (2014) explicitly acknowledged its concern that "trade-offs exist between mitigation and adaptation and among different adaptation responses." One way to reduce the potential for interactions that may nullify strategies or cause maladaptations is to segregate actions in space. The protection of intact communities within climate refugia is a perfectly reasonable strategy, but it may be frustrated by even well-intentioned introduction of novel species, unless these practices are kept separate. Similarly, maintaining historical habitat for an endangered species is incompatible with transformation to a novel or neo-native community that anticipates climate change.

Instead, the three classes of strategies described above—observation, restoration, and facilitation—may be segregated into a portfolio of *zones* in which adaptation options appropriate to each strategy may be implemented. This *portfolio approach* reduces the potential for willy-nilly, countervailing application of adaptation actions by requiring that the purpose of each action be well considered in advance before applying within a specific zone. It also prevents homogenization of the landscape and spreads the risks associated with management action among classes of perceived risk from low (observation) to high (facilitation), much as a stock portfolio allocates investments among risk classes and avoids the problem of "putting all one's eggs in a single basket" (Hummel et al. 2009).

Spreading climate risk across a plurality of management approaches fits well within the application of financial portfolio theory (sensu Markowitz 1952, 1999) to conservation, as described by Figge (2004). Figge suggests that the risks of losing genes, species, and ecosystems, measured in terms of the benefits they provide (e.g., food and medicines), might be managed through the development of "bio-folios," or groupings of genes, species, and ecosystems with optimal risk-return ratios. The benefit of grouping elements in a portfolio derives from the "key rule of portfolio theory: Return is additive and risks partly cancel each other out" (Figge 2004). An important distinction between Figge's approach and what we advocate here is that Figge assigns value and risk to the genes, species, and ecosystems in his portfolio, while we assign risk to the management strategies themselves. Figge proposes investing limited resources (i.e., money) in different sets of species representing different levels of risk and future value. We propose investing limited resources in the three different management strategies representing different levels of risk to maximize future payoff in terms of building blocks.

As with financial portfolios, a portfolio approach to conservation will require the ability to make reallocations in response to monitoring and evaluation of performance in relation to hypothesized outcomes. Financial portfolios may retain a seemingly low yield investment yet do not remain with a poor performer indefinitely. Hunter et al. (2010) state, "Knowing when to stay the course and when to change in the face of uncertainty about climate change and its complex effects on species and ecosystems demands that conservation professionals finally become serious about implementing adaptive management." The portfolio approach, in addition to being a risk-spreading strategy, is necessarily and simultaneously an adaptive management experiment through time. As Lindenmayer and Hunter (2010) suggest, "…a risk spreading approach can lay the foundation for adaptive-management experiments (sensu Holling 1978, Walters 1986, Walters and Holling 1990) and associated approaches such as adaptive monitoring (Lindenmayer and Likens 2009). A risk-spreading approach can allow continuous improvement in the understanding of biodiversity and its response to management interventions (Nichols and Williams 2006)."

Allocating the landscape into a portfolio of three zones also reflects many of the concepts underlying the "Triad" approach to sustainable forestry, originally proposed by Seymour and Hunter (1992) and further developed and applied by Montigny and MacLean (2006). The framework allocates the landscape to three different zones of varying management intensity: ecological reserve, an ecological forestry zone, and a zone of intensive, high-yield forestry. Like the portfolio approach, the Triad is predicated on the logic that no one management strategy is going to meet all objectives, but allocation of the land to a spectrum of management intensity will maximize the values realized at the level of the whole landscape. The portfolio approach also shares with the Triad a humility regarding human management, providing reserves free of management intent along with zones of moderate and intensive management intervention.

As with the Triad, allocation of land to the portfolio approach may be guided by information about current ownership or administrative status, the condition or integrity of the ecosystem, and location or proximity to overriding management concerns, such as community protection from wildfire. As summarized in Table 1, each of the zones has a different purpose as well as a different set of lands most suitable for inclusion. Lands appropriate for the observation zone possess qualities that make them likely to sustain the constituents of future ecosystems without intervention. In general, ecosystems that currently are in good condition and have sustained all their parts can be expected to sustain those parts into the future without assistance better than systems that have already been compromised. The highest quality lands therefore generally make the best candidates for the observation zone, but this zone may also consist of lands that have been restored or have recovered to some semblance of integrity prior to allocation to observation. In addition, lands that have already been allocated through law to receive minimum intervention are appropriate for inclusion. Obviously, lands already designated as wilderness, ecological reserve, or forever wild easements (legally binding commitments by private land owners not to allow any resource extraction) belong in this zone.

Table 1. Summary of the three zones of the portfolio approach with descriptions of intended outcomes and allocation criteria.

Zones	Response to change	Purpose	Suitable lands
Observation	Accept change	To conserve the building blocks of future ecosystems without intervention and therefore without unintended consequences of management. Maintains background rates of change	Designated wilderness, research natural areas, roadless lands, and other lands most likely to sustain ecological integrity without intervention (e.g., areas of high genetic diversity, limited invasive species, and/or late-seral forest)
Restoration	Resist change	To sustain historically whole ecosystems within their historical range of variability. Provides net slower rates of ecological change	Such lands may have been degraded by past management, but can be restored to high ecological integrity through management. Non-wilderness national parks, monuments, wildlife refuges, and other lands set aside specifically to sustain scenery, natural and historic objects, and wildlife are especially appropriate for inclusion in this zone
Facilitation	Guide change	To sustain viable populations and other historical legacies in the face of climate change. Populations, soils, and streams, for example, may be manipulated into a condition that is more resilient to climate change, even if the ecosystem diverges from that which dominated historically. Provides net faster rates of change	Lands best suited for the facilitation zone may have undergone substantial change but are capable of supporting valued ecosystem components under management. Here, heavy-handed activities, such as the artificial cultivation of endangered species, may be appropriate if necessary to sustain wildland values identified by society

Such reserves are not guaranteed to sustain all valued elements and services of ecosystems, but their historical record of success is excellent, and they ought to be part of any strategy to sustain ecosystems in the face of climate change. Landres (2010) identifies a host of benefits of the "hands-off approach," including sustaining non-focal species and hedging against risk. As Landres (2010) discusses, management that is essentially no management, or wilderness, will also provide areas that are free of unintended consequences of active management. Such unintended consequences of management in the past have compromised the very ecological diversity we hope to deliver to the future.

The restoration zone consists of lands managed explicitly to preserve historical ecosystems (Table 1) but that may have been somewhat degraded by past management (e.g., logging, overgrazing, fire exclusion, species invasion). Candidates occur in non-wilderness national and state parks, monuments, wildlife refuges, Bureau of Land Management lands, national and state forests, and conservation easements that permit sustainable resource harvest (e.g., working forest or working ranch conservation easements). Such allocation would make explicit which parts of any planning unit will be dedicated to restoration based on historical conditions. Historical range of variability may ultimately prove to be a poor model of sustainability in the face of climate change, but it remains the only model we have of the dynamics that sustained ecosystems in the past (Lertzman and Fall 1998). Sustaining the whole ecosystem while "swimming upstream" against the current of climate change may ultimately prove impossible (Millar et al. 2007), but it may also buy time for certain species, communities, and processes that might be eliminated in the short term without such human intervention. In the case of fire-prone ecosystems, or aquatic communities at risk due to altered hydrology, restoration may result in ecosystems that are both more resistant to change and more resilient to future disturbances. In contrast to the observation zone, the restoration zone is to be continually managed to sustain its historical integrity, though if monitoring indicates that high integrity can be maintained without intervention, little effort may be necessary.

The third class, the facilitation zone, would consist of the remainder of the landscape (Table 1). Here, the desired future condition would be unconstrained by historical conditions, allowing the testing of new approaches to achieving resilience in the face of climate change by guiding ecological change to conditions believed to be achievable in the face of anticipated climate. The objective here would not be traditional management or release from legal protections. Instead, "resilience thinking" (sensu Zavaleta and Chapin 2010) would apply, where preferred building blocks necessary to sustain ecosystem services would be identified through an open, collaborative, public process focused on ecosystem function, rather than states, and on linkages between ecological and human communities. As Zavaleta and Chapin (2010) note, "Managing for resilience ultimately means managing for the long-term adaptability and functioning of a regional system, even if that means allowing major reshuffling of the ecosystem's parts to take place (without losing parts altogether)." The focus in the facilitation zone would be on anticipating future climate and managing for the present or anticipated ecosystem elements that can thrive under those conditions. Because of the high risk associated with some of the interventionist tactics that may be necessary here, the facilitation zone is likely to consist of the most highly altered, and therefore least contentious, wildlands.

While the condition of the land can be an important determinant in the allocation of the portfolio, it is worth underscoring here that the portfolio approach is not based on what may be called the "medical model," the idea that ecosystems should be treated like patients with an assemblage of normal species that should be maintained over time. The point is not to nurse ailing ecosystems back into a condition of health and then let them go. The point is to spread risk among three strategies applied simultaneously to maximize net retention of building blocks and to learn over time which strategies seem to work best. Table 2 illustrates how these three different strategies may be applied to spread risk across a portfolio for landscapes in the commercially managed native forests of the northeastern U.S., the fire-prone forests of the Sierra Nevada, and the fragmented habitats of the American Southwest. Land ownership and management patterns and dominant ecological stressors interact to dictate the management prescriptions undertaken for a particular landscape. The forests of Maine are largely privately owned, and most conserved land is protected from land-use conversion through working forest easements that allow commercial harvest. Loss of mature forest along with road building and hydrological disruption are significant present-day stressors, while forest conversion forced by changing climate is seen as a significant future ecological stressor. The activities suggested in Table 2 for western and northern Maine forests are contemplated in response to these management constraints and environmental stressors. In contrast, Sierra Nevada forests are largely under the control and management of several federal agencies. Land-use conversion to other uses is not the overriding concern. Increasingly large and intense forest fires are the significant ecological and environmental threat in these landscapes (Miller et al.

Table 2. Examples of how the portfolio approach may be applied in different landscapes.

Landscape	Summary of management situation	Observation zone activities	Restoration zone activities	Facilitation zone activities
Western and northern Maine	Historically contiguous industrial forest landscapes have been broken up and sold off for other land uses, thus reducing and fragmenting habitat and presenting barriers to adaptive movement and processes	Work with willing landowners to establish ecological reserves within working forest easements and other land protection projects to increase lands in non-managed condition	Improve ecological conditions within working forest easements on private lands and other land protection projects through, for example, culvert replacement to allow fish passage, harvest prescriptions to accelerate development of mature forest structure and composition	Include harvest prescriptions designed to encourage establishment and growth of red oak, white pine, and other commercially valuable species that are expected to increase with climate change within working forest easement and other land protection projects
Sierra Nevada fire-prone forests	More than a century of logging of large, fire-resistant trees, grazing of fire-adapted grasses, and suppression of natural fire have facilitated the growth of dense forests that now burn destructively when they cannot be suppressed. Climate change is expected to exacerbate the situation	Allow fires to burn without suppression. Most fires will burn under less-than-extreme conditions, and while they may sometimes produce undesired results, many others will burn with characteristic severity and begin the process of restoring resilience	Restore forest structure and composition typical of the pre-settlement era in which fire regularly burned harmlessly through the forest understory. Prescribed fire will aid the process	Manage the forest into a structure and composition that will be more likely to survive increased fire activity. This may require altering species composition toward a higher proportion of fire-resistant species or maintaining a more open structure than would be considered natural
Sky Islands of the American Southwest	Much of the biodiversity occurs on isolated mountain ecosystems cut off from other such sky islands by developed or otherwise hostile lowlands. Development has already cut off some wildlife populations such as desert bighorn sheep from historically persistent water sources, and climate change is expected to exacerbate water shortages	Observation zones should be established across ecological gradients to increase the ability of species to reach water sources on their own. Species will be allowed to adjust their behavior in response to water shortages, move across perilous terrain, or die	In restoration zones, historical water sources needed to sustain native species can be augmented to maintain historical availability where they remain connected or artificially constructed to mimic historical sources where they have been cut off	Species in danger of extinction in the observation or restoration zone may be translocated and artificially maintained in the facilitation zone. Here, habitat may be manipulated to provide conditions that support socially valued species threatened by changes occurring outside the zone

2009). As Table 2 indicates, the management responses in any landscape reflect the dominant land ownership and overriding stressors.

Application of the Portfolio

So where do we get this portfolio of sites? Fortunately, it is all around us. Virtually every landscape is a mixture of different land classes, including developed lands, undesignated wildlands, and protected areas, each managed with different emphases. Even within protected areas, the International Union for the Conservation of Nature (IUCN 2008) recognizes seven categories, from strict nature reserves, managed solely for the protection of biodiversity, to areas with sustainable use of natural resources, equivalent to general U.S. national forest or BLM-managed lands (Table 3). Each of these classes is governed by a different set of constraints and policies that allow certain activities and prohibit others.

Table 4 details some, though by no means all, of these differences to illustrate the range of activities that distinguish protected area categories. These categories have specific IUCN definitions and are depicted in Table 4 from least ecological impact at the top of the table (monitoring) to greatest ecological impact at the bottom of the table (mining/energy development). At one end of this spectrum are those classes where observation and acceptance of change will predominate; at the other end, more options exist to pursue more active intervention. In any landscape, this range of wildland designations, including those wildlands that have no formal protective status, can be utilized to provide the portfolio of adaptation approaches described here. These protected area categories do not translate directly to a given portfolio allocation; rather, they represent the stock from which a portfolio may be built in a given landscape.

Within a landscape, all zones should be designed according to established principles of conservation biology. In the context of climate change, it remains important to reduce the additive stressors associated with habitat fragmentation, loss, and degradation (Hunter et al. 2010, Trombulak et al. 2012). Moreover, most adaptation mechanisms benefit from ecologically diverse, intact, and connected landscapes. All zones will be more effective at conserving species if they are large and intact, ecologically representative, configured to minimize edge effect, and contiguous enough to facilitate movement at different spatial and temporal scales needed for various life history and population-level events (Noss and Harris 1986, Noss and Cooperrider 1994, Rothley et al. 2004, Hilty et al. 2006, Minor and Lookingbill 2010, Wang and Onal 2016).

Reserve network design has been augmented by the incorporation of geophysical diversity (Anderson and Ferree 2010) and connectivity across physical environmental gradients (Beier and Brost 2010). Greater emphasis is also being placed on diversity at the genetic and population levels (Neel 2008). These are important contributions to our ability to achieve full ecological representation. Other developments include the application of downscaled bioclimatic and ecological envelope models that anticipate where species may move in the future (Schmitz et al. 2015). The portfolio approach described here incorporates notions of size sufficiency, configuration, connectivity across gradients, ecological representation, and diversity into the designation of all three zones, but rather than identifying the minimum reserve system sufficient to protect existing biodiversity, it allocates the entire landscape to a suite of strategies that in combination will help spread climate and management risk.

Unfortunately, while most landscapes contain some mix of wildland categories, wildlands are often relegated to the higher end of elevational gradients and are therefore not ecologically representative of the full diversity of life and often exist as isolated fragments not ecologically linked to other wildlands (Aycrigg et al. 2013, 2016). Achieving desired configuration and representation will require changes in the allocation of protected area categories.

Table 3. IUCN protected area categories and management descriptions.

IUCN category	Definition
Category Ia: strict nature	Strictly protected areas set aside to protect biodiversity or other features, where human visitation, use, and impacts are strictly controlled and limited
Category Ib: wilderness area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation
Category II: national park	Large natural or near-natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area
Category III: natural monument or feature	Areas set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove
Category IV: habitat/species management area	Areas designated to protect particular species or habitats and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category
Category V: protected landscape/seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural, and scenic value
Category VI: protected area with sustainable use of natural resources	Protected areas that conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. In general, unreserved portions of national forests and BLM-managed lands, working forest easements, and working ranch easements are typical

Table 4. Management activities allowed in different IUCN protected area categories.

Activity	Ia. Strict nature reserve	Ib. Wilderness area	II. National park	III. Natural monument	IV. Habitat Management Area	V. Protected Landscape	VI. Sustainable use
Monitoring	✓	✓	✓	✓	✓	✓	✓
Light-touch scientific research	✓	✓	✓	✓	✓	✓	✓
Education	✓	✓	✓	✓	✓	✓	✓
Low-impact recreation/ non-motorized visitation		✓	✓	✓	✓	✓	✓
Fishing		✓	✓	✓	✓	✓	✓
Subsistence activities		✓		✓	✓	✓	✓
Hunting		✓		✓	✓	✓	✓
Livestock grazing		✓		✓	✓	✓	✓
Motorized and tourism infrastructure			✓	✓	✓	✓	✓
Prescribed fire			✓	✓	✓	✓	✓
Non-extractive vegetation management			✓	✓	✓	✓	✓
Intensive research				✓	✓	✓	✓
Drainage or irrigation					✓	✓	✓
Cultivation					✓	✓	
Supplemental feeding					✓	✓	
Sustainable cultural use						✓	
Sustainable resource extraction							✓
Mining/energy development							✓

Where public lands abound, many of these changes, such as the designation of research natural areas and the allocation of land to wilderness, can be achieved within existing administrative units. Others, such as the designation of national park land and wildlife refuges, will require changes in administration. Some of these changes can be achieved through administrative processes, including the national forest planning process, while others will require an act of Congress. Ensuring that these changes result in a landscape better configured for adaptation will require cooperation across all parties, including the involvement of the public in decision making. Such changes as these may seem insurmountable, but it has taken more than a century to achieve the existing configuration of protected areas. There is no reason why concerted effort by all parties over the next several decades cannot result in improved configurations better suited to inevitable climate change.

While implementing the portfolio is conceptually simpler on public lands, it is no less possible in regions dominated by private lands, such as the U.S. Acadian forest spanning the Adirondacks, Vermont, New Hampshire, and Maine. In Maine, the current allocation of conservation lands is dominated by multiple-use, private, working forest easements, while land under some type of reserve management expressly for the conservation of biological diversity is very limited. Here, the portfolio approach may provide an impetus for undertaking conservation projects that include allocation of high integrity lands to observation management.

Conclusion

The uncertainty that attends climate change requires a conservation approach that applies a plurality of strategies and spreads climate and management risks among them. It is not currently clear what the best approach will be to ensure that the building blocks of future ecosystems survive in the face of climate change. Some have argued that the pressure of climate change should lead to "designating new protected areas and undertaking low-level habitat management to reinforce species' intrinsic dispersal and migration mechanisms" (Dawson et al. 2011), while others have suggested that "accepting that the future will be different from both the past and the present forces us to manage forests in new ways" (Millar et al. 2007). A third perspective invokes Aldo Leopold's still-relevant "first precaution of intelligent tinkering" to keep all the parts (Leopold 1953), even if it is "swimming upstream" (Millar et al. 2007). Ultimately, climate change will operate on what exists, and it is therefore essential to conserve as much of our natural heritage as possible through a diversity of coordinated strategies. A portfolio of approaches, where some areas are managed creatively and deliberately to anticipate climate change and conserve a subset of building blocks that will promote certain ecosystem services and values, some are managed to maximize the integrity of our natural heritage, and the rest is left for nature to change on her own time, in case we are wrong elsewhere, can provide a framework for diverse strategies while spreading risk among a portfolio of risk classes.

Global change requires purposeful application of retrospective and prospective management in order to avoid rapid loss of the biological legacy of millions of years of evolutionary change. Moreover, a plurality of approaches is being applied already, but in no coordinated fashion with a strong likelihood of maladaptation and no formal mechanism to learn from experience. The portfolio approach provides a framework to design and improve our conservation networks with the full range of management options available. We conclude that there is, more than ever, a role for reserve-style management and that this land allocation should be steered toward areas of high ecological integrity. Similarly, we have established the case for active intervention outside of reserves.

Far from being a radical innovation in land management, the idea of allocating land to zones that span ecological gradients has deep roots. The ancient Hawaiians instituted a system, called ahupua'a, that conferred land grants to individual families that transcended elevation from mountaintops to the sea, thus ensuring that every family had access to a full range of resources and providing the opportunity to migrate as resource availability changed (Fig. 4). That same kind of approach, allocated by conservation strategy rather than by family, could ensure that a full range of values persists, even in the face of climate disruption.

Still, we do not expect managers to suddenly abandon traditional designations or land uses and adopt the portfolio approach. Instead, we view the portfolio approach as an overlay on top of existing allocations that can guide decisions to apply adaptation options within zones. If the portfolio approach is to aid adaptation, it must be applied within existing planning processes and reflect the realities of conditions on the ground. The portfolio approach is just that, an *approach* to conservation, not a strict prescriptive plan. Our intent is for this framework to provide guidance for the use of plural approaches, spatially segregated and applied to reduce risk to the

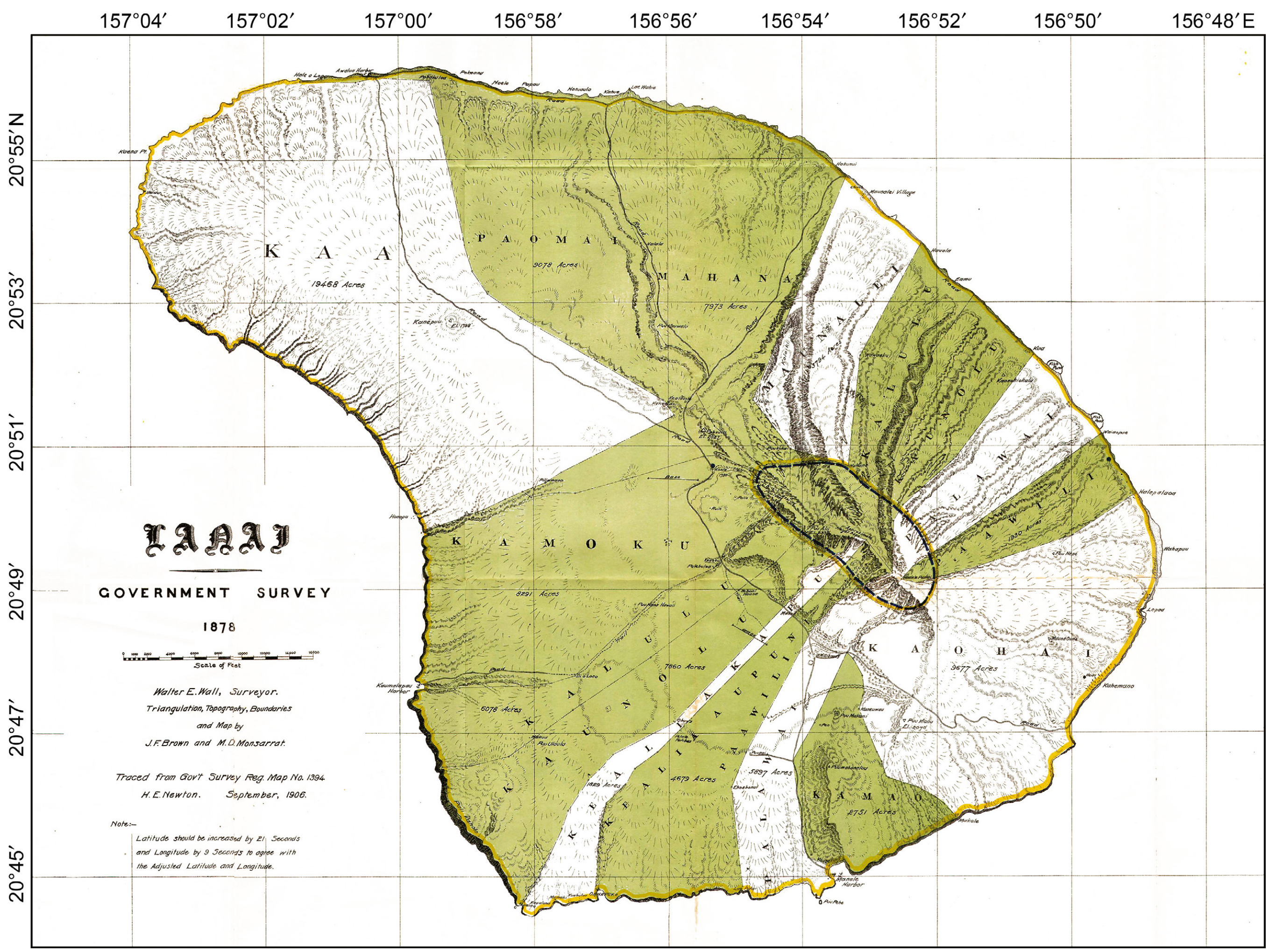

Fig. 4. Map of the Hawaiian Island of Lanai in 1876 showing the distribution of ahupua'a, or family ownerships that spanned the entire elevation gradient of the island. The map cite from: https://upload.wikimedia.org/wikipedia/commons/7/7d/1878_Government_Land_Office_Map_of_Lanai,_Hawaii_-_Geographicus_-_LanaiHawaii-lo-1878.jpg

maintenance of ecological building blocks. We have suggested existing land management allocations as a starting point for allocations to a portfolio; however, actual allocation must be conceived and practiced in the context of each subject landscape.

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