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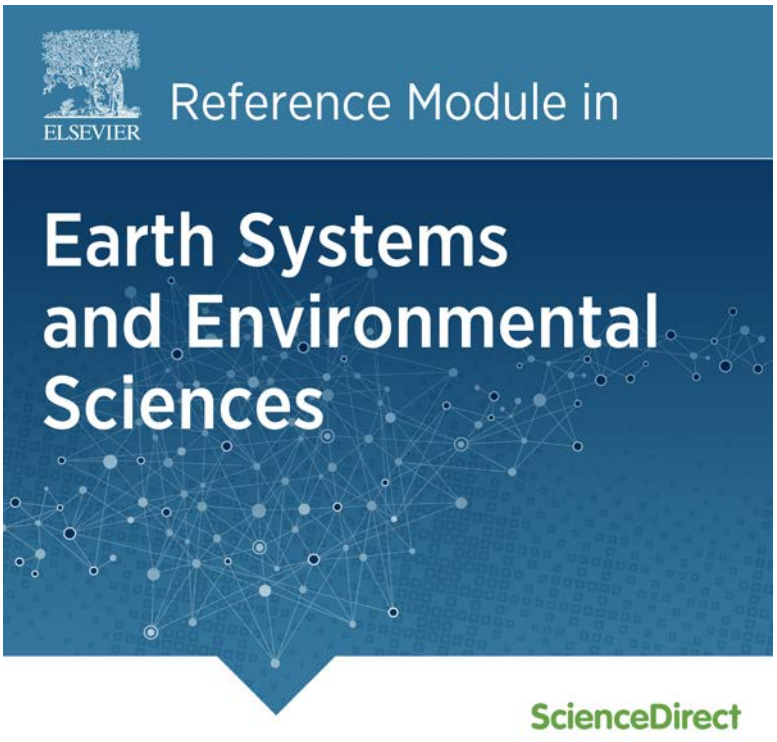

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Implementing Portfolios of Adaptation Strategies on U.S. Conservation Lands in the Anthropocene

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Introduction

Conservation biologists and resource managers used to assume that ecosystems function within a range of natural variability (Milly et al., 2007). Climate and biome boundaries were considered stable. Policies and management strategies measured success via comparisons to a historical or natural condition (Cole and Yung, 2012; Magness et al., 2012). The plants, animals, ecosystem types, and ecological processes (i.e., hydrological and disturbance regimes) thought to be present within the boundaries of conservation units before European settlement were maintained or restored. Conservation planning mainly focused on building reserve networks that represented and maintained the current distributions of species and ecosystems.

The Anthropocene is a new geologic epoch where humans drive Earth systems as much or more than other natural processes. Our economic and social systems are interlinked with ecological systems. Disturbance or change to any part of the system can rapidly cascade to affect large areas (Steffen et al., 2011). Unlike in the Holocene, ecosystems are now assumed to be transient and path dependent. No place on Earth sits outside of human influence. Future ecosystems will be different and perhaps surprising and without a known analog (Williams and Jackson, 2007)

In our rapidly changing world, managing conservation units based on past or natural conditions may no longer be possible. Managers need strategies to navigate ecological persistence and change (Stein et al., 2013). Ecosystem stewardship is an action-based framework that suggests resource managers should shape change proactively to foster sustainability of social-ecological systems (Chapin et al., 2010). We can shape change using retrospective approaches that work to maintain or restore historical conditions. Another option is shaping change with prospective approaches that focus on aligning systems to future conditions (Magness et al., 2011). In this article, we provide an overview of ecosystem stewardship and provide three conceptual approaches for strategically implementing portfolios of adaptation actions across conservation networks.

Stewarding Persistence and Change

Ecosystem stewardship provides a framework for land management in the Anthropocene (Chapin et al., 2010). The framework assumes ecosystems are complex systems that are path dependent and coupled with human systems. Therefore, the reference for success is sustained ecosystem services that are not wed to historical condition. Ecosystem services are the ecological processes and products that maintain human well-being (Millennium Ecosystem Assessment, 2005). Ecosystem services, such as clean water and air, have value because they support life and the ability for ecosystems to be self-sustaining. Maintaining ecosystem services aligns with conservation values because functioning ecosystems and biodiversity are central goals.

Resilience, Vulnerability, and Adaptation

Ecosystem stewardship considers both ecological persistence and change. Vulnerability assessment is an approach to understanding the likelihood of persistence and change. Vulnerability assessment can help managers identify hazards and stressors that are likely

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to transform ecological conditions (Glick et al., 2010). Once key vulnerabilities are identified, managers use adaptation strategies to increase the resilience of the system. The concept of resilience has expanded in meaning as it conceptually evolved in multiple disciplines (Davidson et al., 2016). When implementing adaptation, it is important to have clarity on the context and meaning of what is being managed for resilience (Carpenter et al., 2001).

Basic resilience

The goal of enhancing basic resilience is to maintain current conditions. Basic resilience can be increased by focusing on reducing stressors (resistance) and increasing the likelihood that the system can absorb and recover from disturbance (Davidson et al., 2016; Millar et al., 2007). Persistence approaches are retrospective adaptation; they use a known current historical baseline of ecological understanding to guide management actions and managers generally have more experience using them (Magness et al., 2011). For example, retrospective adaptation approaches have been suggested to maintain favorable hydrologic conditions for Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) (Cross et al., 2012). Basic resilience can be increased by maintaining peak spring flow to reduce the potential for competitive interactions with a nonnative trout species. Cross et al. (2012) identify potential management actions to steward conditions toward persistence, such as installing snow fences to maximize available snowpack for runoff, constructing dams to control flow timing, and securing water rights.

Adaptive resilience

Change will also happen. Current and past conditions may no longer be possible. The ecosystem stewardship framework includes proactive strategies to cope with and shape change (Chapin et al., 2010). Adaptive resilience is prospective and explicitly acknowledges that ecological systems may not return to their original state after disturbance. Therefore, the focus of adaptive resilience is to increase the likelihood of the system to maintain the same identity, to renew and reorganize after disturbance and to adapt to the new conditions (Davidson et al., 2016); in other words, the focus is on the capacity of the system to respond to change. As a general rule of thumb, managers should maintain future opportunity. For conservation management, opportunity can be considered the building blocks of future ecosystems, which are the legacies of evolutionary process (biodiversity) and slow-forming geologic processes (soil, landforms) (Aplet and McKinley, 2017). Species are moving across the landscape with climate change, so the building blocks of biodiversity are more transitory on conservation units than physical features from geologic processes. Land managers should prioritize actions to minimize species extinction in order to maintain global diversity (Magness et al., 2011). At the local level, managers can consider how biodiversity influences the range of conditions that can be tolerated (response diversity) and the diversity of ecological functions (functional diversity) (Chapin et al., 2010). The building blocks of future ecosystems may provide enough adaptive resilience to allow ecosystems to adjust to changing climatic conditions without losing functionality or future opportunity. In these cases, land managers may be able to allow change to occur naturally without human intervention (drift) (Aplet and McKinley, 2017; Magness et al., 2011). More passive management approaches, such as maintaining ecological connectivity, accepting change and allowing ecosystems the opportunity to respond to new climatic conditions and disturbance regimes (Millar et al., 2007). For management institutions, adaptive resilience is increased by increasing the ability of managers to be flexible and nimble in order to respond to emerging conditions (Chapin et al., 2010).

Transformative resilience

Ecological transformations can occur rapidly once critical thresholds are exceeded. Here, the focus is on transformative resilience or the ability of the system to transform to a new, functionally different system that is aligned with new conditions (Davidson et al., 2016). Facilitated transformation, where the future trajectory is actively shaped, is necessary in cases when change results in ecological degradation, such as depauperate or cosmopolitan ecological communities or the loss of ecological function (Chapin et al., 2010). Our ability to proactively shape change is enhanced by opportunities to actively learn from one another about successful or failed actions and emerging conditions in various localities. Preparing for facilitated transformation will require that we can identify plausible alterative future conditions and the thresholds, triggers and pathways that would need to be navigated. Facilitated transformation also requires stakeholder engagement to raise awareness about future options and to collectively identify undesirable futures. For land management agencies, stakeholders will include local communities that live in the affected region as well as stakeholders with national-scale interests that are guided and constrained by legislation such as the Endangereds Species Act and the Wilderness Act. Navigating ecological transformation will require managers and scientists to engage with stakeholders in more collaborative, transparent and adaptive processes (Magness and Clark, 2017). Facilitated transformation does not imply that management interventions will be required to maintain the new ecosystem over the long term. Instead, managers should be helping the ecosystem realign to new conditions with actions such as translocating species or managing colonization after disturbance (Millar et al., 2007). Successful facilitated transformation will result in a resilient, self-sustaining and self-organizing ecosystem that does not require constant management to maintain. In other words, we do not assume that humans control transformed systems; transformation results in wild and self-willed systems that align with new conditions.

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Adaptation Strategies

How can managers decide when to steward persistence or change? When should managers realign species and transform ecosystems to new conditions? These are not simple questions and there is no right answer (though there may be wrong answers). Vulnerability is not uniform across the landscape and this spatial variation may be useful for evaluating adaption options on conservation lands (Fig. 1). Vulnerability assessments consider exposure, sensitivity and adaptive capacity (Glick et al., 2010). Exposure is the magnitude and rate of climate change that is or will be experienced. Sensitivity is related to the likelihood a species or ecosystem will be affected by change. Adaptive capacity is the ability to cope with change. For geographic analysis, sensitivity and adaptive capacity can be linked with spatial features such as ecological intactness, ecological gradients, and location within range boundaries (Magness et al., 2011; Watson et al., 2013).

Gradients of exposure, sensitivity and adaptive capacity can inform which suites of adaptation approaches are the most likely to succeed (Fig. 1). The rate and magnitude of change (exposure) will influence the practicality of retrospective and prospective adaptation approaches (Aplet and McKinley, 2017; Magness et al., 2011). Localities with slower or less pronounced change will be more likely to maintain current or historical conditions into the foreseeable future. On the other end of the spectrum, locations with high exposure to climate change and other stressors are more likely to exceed thresholds and transform to novel systems; therefore, prospective adaptation that focuses on future conditions will be useful. The gradient of sensitivity and adaptive capacity can help delineate the need for management intervention. Species and ecosystems that are not sensitive to change or have high adaptive capacity may be more suited to low intervention approaches. Conversely, highly sensitive species and ecosystems that also have little adaptive capacity may require more intensive management intervention.

Locations with slower rates of change, low sensitivity, and high adaptive capacity may be well-suited to serve as refugia for the species and ecosystems that occur there. Refugia can be stewarded into the near future using retrospective and low-intervention approaches that seek to maintain current conditions. Locations with slower rates of change, highly sensitive species or ecosystems with low adaptive capacity may be suited for stewardship actions that rely on well-established management practices to maintain or restore historic conditions. For these places, conservation practices such as increasing landscape connectivity, reducing hunting pressure or other mortality factors, and managing invasive species can reduce anthropogenic stressors that are not related to climate change exposure.

Other locations will have relatively higher rates and magnitudes of change. Areas with high exposure, low sensitivity and high adaptive capacity may be places where we can steward "natural" adaptation with little to no active management intervention. These locations provide a testing ground for how systems will re-organize and change based on current ecological legacies (drift). Managers can steward change by carefully observing drift to assess the if these places can maintain future opportunity (biodiversity and physical legacies) and retain functional, though different, ecosystems (Aplet and McKinley, 2017). Locations with high exposure, highly sensitive species and ecosystems, and low adaptive capacity may need greater levels of intervention to facilitate transformation to an ecosystem that is more aligned with future conditions. Facilitated transformation does not imply that the novel ecosystem will need continual interventions; rather, the goal should be a self-sustaining and self-organizing (albeit novel) system.

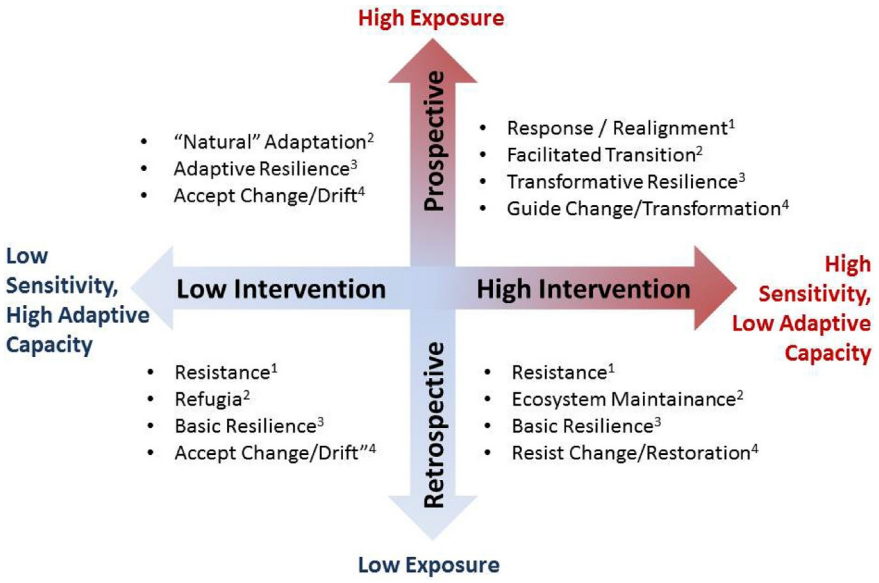

Fig. 1 Conceptual diagram of how suites of adaptation strategies relate to vulnerability assessment. The axes represent the components of vulnerability. The relative amount of exposure influences the efficacy of prospective and retrospective approaches. Sensitivity and adaptive capacity influence the amount of management intervention that may be required. Suggested suites of adaptation strategies are listed in four zones using terminology from (1) Millar et al. (2007), (2) Magness et al. (2011), (3) Davidson et al. (2016), and (4) Aplet and Mckinley (2017).

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Stewarding Conservation Lands Using Portfolio Approaches

There are inherent trade-offs in choosing adaptation strategies. Conservation and land management involves social and ethical values that are always intrinsic in our choices, but may not be explicitly recognized (Cole and Yung, 2012; Magness et al., 2012). There are clearly ecological risks and uncertainties when considering intervention, but nonintervention also has serious consequences, such as depauperate ecosystems, loss of genetic diversity, novel assemblages composed of injurious and invasive biota, mass extinction, or loss of future opportunity. Land managers may want to apply a variety of approaches, as opposed to choosing one strategy, as they act in the face of uncertainty. Aplet and McKinley (2017) use the analogy of a financial portfolio because portfolio approaches bet-hedge to spread risk and reallocate resources based on performance.

Here, we outline three conceptual approaches to how land management portfolios could be strategically organized to address uncertainty and risk using the Kenai National Wildlife Refuge as an example. In the first approach, conservation units within a system (in this case, the National Wildlife Refuge System) are managed differently but coherently as a system. In the second approach, conservation units managed by different agencies respond differently but deliberately to a warming climate consistent with their retrospective missions. In the third approach, a given conservation unit applies a management portfolio that explicitly recognizes both retrospective and prospective goals, ultimately favoring one or the other based on performance (i.e., adaptive management). We need to be strategic about how we apply retrospective and prospective adaptation because they can work against one another in maladaptive ways (Denton et al., 2014).

Conservation System Portfolio

Adaptation portfolios for continental or other large-scale conservation networks can leverage gradients of exposure, sensitivity, and adaptive capacity for adaptation planning. When conservation units are managed as a system, conservation risk and experimentation can be spread across the network. Each unit is part of the larger conservation portfolio and adaptation strategies can be designed and coordinated based on the relative vulnerability of the unit within the larger conservation system.

There is a history in the United States of linking individual units into conservation networks. For example, the National Wildlife Refuge System used migration flyways of waterfowl to coordinate refuge management at a continental-scale. In 1997, the National Wildlife Refuge System Improvement Act legislated that the 550 refuge units be managed as a coordinated conservation system (Fischman, 2003). Coordinated, continental conservation networks, such as the refuge system, will be crucial given that species move in response to climate change. The same large-scale coordination will be needed as plants and animals redistribute across continents.

A transparent and collaborative planning process will be necessary for this approach to be relevant to stakeholders. For example, a general analysis of the vulnerability of conservation units would consider different factors than a more specific vulnerability assessment of a species across the current and future range. Similarly, a vulnerability assessment focused on sea-level rise would look very different than a vulnerability assessment focused on the consequences of heat stress on moose. Stakeholders will need to define the problem and scope of the vulnerability assessment to identify relevant factors to consider and to build the communication and support necessary to implement. Furthermore, the context of large-scale vulnerability assessment may need to be balanced with the realities of how climate change impacts are affecting local areas and regional resources. Global and North-American vulnerability assessments suggest that Alaska has relatively high climate change exposure, but low sensitivity and high adaptive capacity based on ecological intactness (Magness et al., 2011; Watson et al., 2013). These assessments would conclude that Alaska conservation lands be stewarded using natural adaptation approaches. However, as an example, many arctic species rely on sea ice and these species are facing high exposure, high sensitivity and unknown adaptive capacity. These ice-dependent species may need intervention to avoid extinction even though the terrestrial landscapes in Alaska are relatively intact.

Spatial vulnerability portfolio example

The Kenai National Wildlife Refuge is one of over 550 refuges in the National Wildlife Refuge System. The National Wildlife Refuge System aspires "to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans" (National Wildlife Refuge System Improvement Act 1997). Refuges vary across the National Wildlife Refuge System in terms of exposure (relative temperature change), sensitivity (proximity to biome edge and presence threatened or endangered species), and adaptive capacity (ecological intactness and available climate gradients). Based on these criteria, the Kenai National Wildlife Refuge could serve as a location for allowing natural adaptation strategies (Magness et al., 2011). In this portfolio, the Kenai National Wildlife Refuge would provide knowledge about the consequences and benefits of allowing ecosystems to drift without human intervention as part of a continental-scale, coordinated adaptation strategy (Fig. 2).

Land Designation Portfolio

Conservation lands in the United States vary in term of ownership and purpose. National Wildlife Refuges are oriented toward fish and wildlife conservation (National Wildlife Refuge System Improvement Act 1997) and National Parks toward preservation (An Act to Establish a National Park Service 1916). Bureau of Land Management lands and National Forests are managed for multiple purposes including conservation, recreation, and the sustained yield of natural resources (Sundry Civil Appropriations Act 1897;

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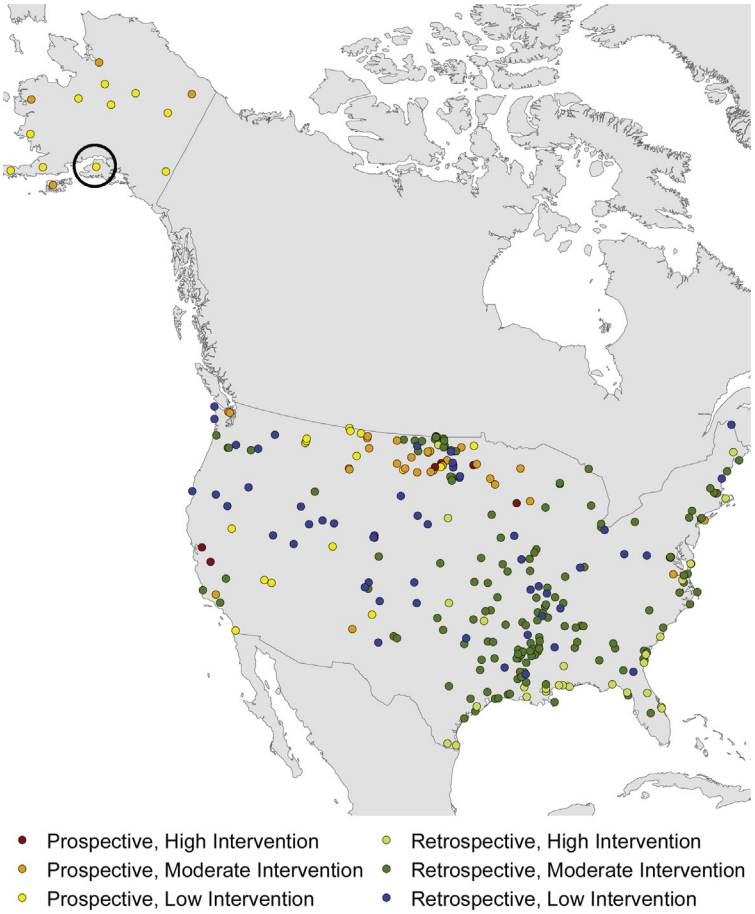

Fig. 2 The Kenai National Wildlife Refuge, located in Alaska (*circled*), is one unit in the larger National Wildlife Refuge System. Vulnerability assessments can identify how different units will experience different levels of exposure, sensitivity, and adaptive capacity. In this analysis, this refuge may serve as a place to invest in low intervention, prospective adaptation strategies. Modified from Magness, D.R., Morton, J.M., Huettmann, F., Chapin III, F.S., McGuire, A.D., 2011. A climate-change adaptation framework to reduce continental-scale vulnerability across conservation reserves. *Ecosphere* **2**, art112.

Federal Land Policy and Management Act, 1976). Other legislation also influences how lands are managed. The Wilderness Act of 1964 requires that land be managed with minimal human intervention. The Endangered Species Act of 1973 influences the management of lands designated as critical habitat for threatened and endangered species.

The legislated mandates, missions, policies, and agency culture dictate which adaptation strategies are deemed to be acceptable to implement on conservation lands (Magness et al., 2012). These differences can be leveraged into a portfolio that can spread risks across the regional landscape (Aplet and McKinley, 2017). For example, Congressionally designated wilderness and National Parks may be less amenable to approaches that require intervention (Cole and Yung, 2012). Lands governed by policies and legislation that are wed to historical condition may be best suited for retrospective approaches initially. In contrast, lands with resource extraction may have opportunities to experiment with facilitated transformation in areas where restoration is needed after development.

A portfolio of adaptation approaches that leverages land designation may be useful for near-term planning. In the next 20–30 years, uncertainty about potential ecological trajectories may be high. Multijurisdictional landscapes can be leveraged for experimentation. Building a land designation portfolio will require communication about practices and visions for the future. Land managers can use this engagement as an opportunity to clarify understanding about the legislative mandates, policies, and values driving management. Communication will increase knowledge about likely ecological trajectories. This type of portfolio is best suited to be implemented across ecologically similar regions with more homogenous vulnerability.

Land designation portfolio example

The Kenai National Wildlife Refuge is located on the Kenai Peninsula in south-central Alaska. Approximately two thirds of the 6-million-acre peninsula are in three conservation units administered by federal agencies with different mandates (Fig. 3). These competing mandates can be leveraged in an adaptation portfolio. The Kenai National Wildlife Refuge has mandates and policies that emphasize natural diversity. In contrast, the Chugach National Forest is focused on natural processes and stable wildlife populations and the Kenai Fjords National Park is concerned with unimpaired environmental integrity without human influence. Given these differences, these

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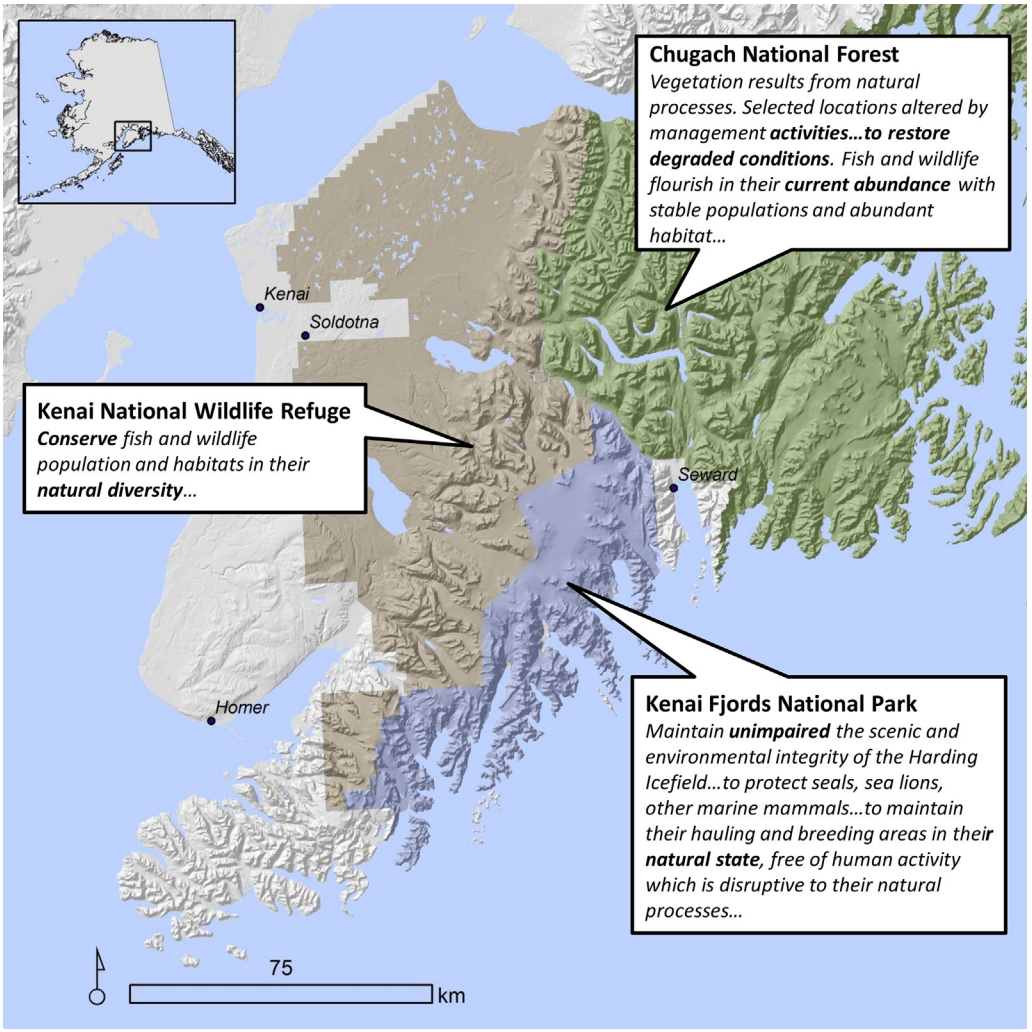

Fig. 3 The Kenai Peninsula in south-central Alaska has three federal land management units that have different mandates. Each unit could adopt a different adaptation strategy but still be explicitly coordinated in an adaptation portfolio for the peninsula.

land units may be poised to play different roles in a coordinated adaptation portfolio. Kenai Fjords could serve as a place where ecosystems are allowed to drift without human intervention. Chugach National Forest may be a good location to experiment with interventions that try to maintain current populations even as change occurs (basic and adaptive resilience). The Kenai National Wildlife Refuge could experiment with facilitating change to ensure ecosystems maintain diversity. Together, the different agency priorities would ensure that the risk of intervention and nonintervention are spread across the peninsula. In addition, the variety of approaches will increase understanding of the efficacy of different approaches so that resources can be reallocated away from failed or maladaptive strategies.

Multiple Actions Portfolio

Proactively shaping ecological change requires an understanding of potential ecological trajectories, system stressors, and thresholds of change. Even with rigorous observations, managers may have incomplete and uncertain evidence about potential future trajectories. Locally, managers can create a portfolio of retrospective and prospective adaptation approaches to bet hedge across diverging scenarios. Heavy investment in retrospective approaches may be prudent early to maintain current conditions as long as possible, while also investing in experimentation across a range of potential future trajectories (Fig. 4).

As managers learn about potential futures and directional change amplifies, adaptation efforts can be reallocated to successful prospective approaches. In other words, we expect retrospective management actions to gradually shift to prospective actions as directional change unfolds. Piloting prospective approaches also provides opportunities to inform stakeholders about alternative future pathways and to receive feedback about which futures are considered unacceptable. Wrestling with the potential range of historical and novel conditions that are possible for a given locality can provide insight into the tradeoffs between choices we are making today and opportunities for the future. In some cases, the choices we make today will limit the viability of some potential futures (Denton et al., 2014).

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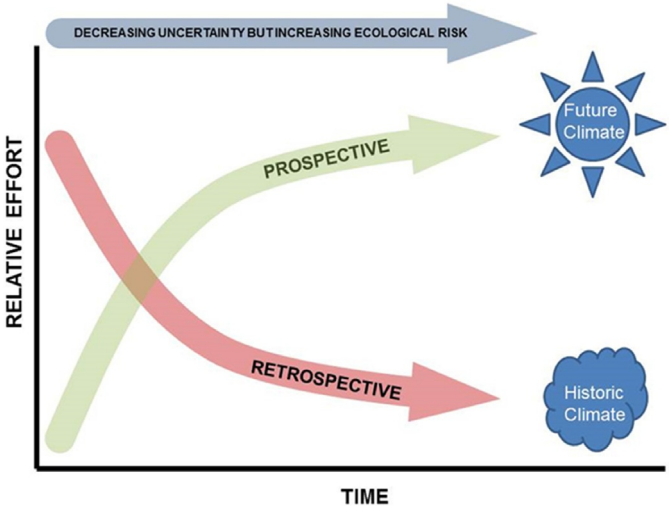

Fig. 4 Conceptual diagram of how retrospective and prospective management can be employed together on a conservation unit. With time, uncertainty about the future trajectory will decrease, but ecological risk (i.e., extinction, lost opportunity, and commitment to an unwanted ecological trajectory) is likely to increase. The relative management effort in retrospective approaches should decrease over time and the relative management effort in prospective approaches should increase.

Multiple actions portfolio example

The Kenai National Wildlife is already experiencing warmer winters and a longer growing season. Changing climatic conditions have made the region more hospitable to exotic plants. Two plant species that occur naturally in western Canada, but introduced recently to the Kenai Peninsula provide an example of a multiple actions portfolio (Fig. 5). *Elodea canadensis* x *nuttalli* is an aquatic plant native to Canada and the contiguous United States. Likely introduced to Alaska through the commercial aquarium trade in 1982, elodea has been aggressively treated with herbicides on lands surrounding the Kenai National Wildlife Refuge since being detected in 2012. This retrospective, high intervention approach will continue until elodea is eradicated from the peninsula or we find that the vectors transporting elodea, such as float planes and boats, are overwhelming eradication efforts. Because elodea has the potential to adversely affect salmon populations, which are ecologically, economically and socially important in the region (Schwörer, 2017), a retrospective management approach is warranted.

In contrast, lodgepole pine (*Pinus contorta*) is a coniferous tree native to Canada, southeastern Alaska and the contiguous United States that is being managed prospectively outside refuge boundaries. Lodgepole pine was introduced to the Kenai Peninsula at least as early as 1973 by landowners who planted it as an ornamental, in fuel breaks, and for timber production, particularly in more recent years to replace trees killed by an unprecedented spruce bark beetle epidemic (Berg et al., 2006). With milder climate conditions, the pine has become naturalized and now is reproducing. Climate envelope models suggest that the potential distribution of lodgepole pine has shifted considerably north and west of its historical distribution, but other factors may be limiting the range shift (Hamann and Wang, 2006). Although lodgepole pine has not been deliberately planted on the Kenai National Wildlife Refuge, it is not actively managed to exclude them from the refuge. Currently the pine is being observed to understand the viability of the pine to colonize the refuge; a low intervention, prospective approach. In a more active prospective approach, management could shift towards actively planting lodgepole pine on the refuge to maintain a forested ecosystem that is more aligned with emerging climate conditions.

Conclusions

In the Anthropocene, conservation units will experience directional change. Directional change will require that managers navigate persistence and change of ecological systems. Ecosystem stewardship provides a framework for how managers can navigate persistence and change. Retrospective approaches use current or historical conditions as benchmarks. When stewarding conservation lands to maintain current or restore historical conditions, managers can reduce other stressors or increase the ability of the system to absorb change (basic resilience).

When the current state is no longer possible to maintain, ecosystem stewardship can provide guidelines for how managers can shape change to maintain future opportunity and the building blocks of future ecosystems (adaptive resilience). Future opportunity is provided by ecological diversity and physical legacies, such as soil and hydrology. In some cases, we can allow systems to drift and adapt naturally to new conditions without losing future opportunity. However, facilitated transformation may be necessary in cases where ecosystems are likely to become depauperate, cosmopolitan, or lose ecological function (transformative resilience). Strategies that steward change are prospective; they have no known benchmark by which to plan management actions and are instead aligned with emerging conditions, with the ultimate goal of achieving the capacity to self-organize and be sustainable without intervention.

Portfolio approaches can help us navigate change because they allow us to invest in a variety of approaches to bet-hedge and spread vulnerability risk. Resources can also be reallocated to portions of the portfolio that are successful; that is, adaptive management (Nichols et al., 2011). Adaptation portfolios can be structured in a variety of ways. We can invest in a spatial

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Fig. 5 The Kenai National Wildlife Refuge is managing invasive species using retrospective and prospective approaches. Elodea (*top* from Cheryl Anderson—USFWS) is an aquatic invasive being managed to exclude it from the Kenai Peninsula. Lodgepole pine (*bottom*) is being monitored with little effort to exclude it from the peninsula.

vulnerability portfolio in which conservation units are managed as a networked system and each unit functions differently based on the geographic context of vulnerability. We can structure a land designation portfolio where different land-based agencies or organizations steward outcomes that are most aligned with their mission and mandates. We can also build a multiple actions portfolio where a range of retrospective and prospective approaches are tried concurrently in a conservation unit. In a multiple action portfolio, we expect that in time resources will be reallocated to more prospective approaches as directional change becomes more pronounced and uncertainty about emerging conditions decreases.

Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of any government agencies.

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