Rethinking Conservation Practice in Light of Climate Change

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ABSTRACT

Predicted changes in climate present unusual challenges to conservation planners, land managers, and restoration efforts directed toward preserving biodiversity. Successful organisms will respond to these changes by persisting in suitable microsites, adapting to novel conditions, or dispersing to new sites. We describe three general categories of strategies for restoring and managing natural systems in light of likely changes in future climate that collectively embrace many of the approaches that The Nature Conservancy is applying or considering in the state of Washington. *Component redundancy* suggests that in natural systems greater ecosystem resilience, despite changing climates, may be achieved by increasing species and community redundancy. *Functional redundancy* is the idea that different components of a system can fulfill the same functions, thereby producing the same result. Restoration projects and managers of natural systems can introduce ecologically equivalent species or novel associations of species, which may help avoid losses in biodiversity. *Increased connectivity* suggests that success is achieved by ensuring that suitable habitats are always within easy reach of one another. This includes conservation approaches that provide linkages, corridors, or other mechanisms to facilitate the movement of organisms as they respond to climate changes. We acknowledge that these approaches are not without risk, nor do they necessarily ensure success. However, we propose them as potential solutions among a growing suite of alternative strategies for incorporating climate change into conservation actions.

Keywords: climate change, conservation management, global warming, Pacific Northwest, restoration

Introduction

The conservation of all biodiversity is a monumental undertaking. Yet, if predictions of rapid changes in climate prove correct, conservation practitioners will soon be confronted with new and even greater challenges. As climatic changes alter environmental conditions, many species in nature preserves and other conservation areas may find themselves in increasingly unsuitable habitats. As on-the-ground conservation practitioners, we are developing hypotheses and strategies for preserving, restoring, and managing lands to conserve biodiversity over the long term in the face of changing climates (Hannah et al. 2007, Heller and Zavaleta 2008). While new and more spatially explicit climate scenarios are developed every day, progress is slower in increasing our understanding of how species and ecosystems may be impacted by climate change and of what practical steps restorationists and natural area managers should be considering today (Hulme 2005, Cole et al. 2008, Lindenmayer et al. 2008, Lawler et al. 2009).

This paper has grown out of our collective experience and conversations with other practitioners regarding the challenges associated with implementing conservation strategies that consider the impacts of climate change. We briefly summarize the ways in which organisms may respond to climatic change and then explore some practical conservation approaches in restoration and management contexts that might facilitate these responses. Similar approaches also can be applied to communities and ecosystems, and we illustrate them for both organisms and ecosystems with case studies from our conservation work in Washington State. Some of these approaches are supported by current conservation biology theory; others are more conjectural. However, the urgency of the issues posed by climate change demands a timely response. We urge restorationists and managers to consider and debate the approaches proposed here, to develop innovative strategies for applying those that seem most appropriate in an adaptive management context, and to document practices and results to permit continued assessment of success, reformulation of hypotheses, and further refinement of strategies.

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Organismal Strategies, Community Stability, and Ecosystem Resilience

The paleoecological record suggests that organisms can respond in three ways to climatic changes (Davis et al. 2005). First, they may persist in suitable microsites or other refugia in otherwise unsuitable habitat ("persistence"). Second, they may adapt through either behavioral changes or selection of genotypes better adapted to novel conditions ("adaptation"). Third, they may shift to a new site by migrating or otherwise altering their range ("dispersal"). Our assumption is that developing more effective methods for enhancing these responses is an important strategy for managers seeking to counteract the stresses that climatic changes may impart to many species.

We suggest that the likelihood of a species persisting at a site despite climatic changes depends to a considerable extent on the resilience of the underlying ecosystems. Here, we use the term resilience to mean the capacity of ecosystems to persist and to absorb change and disturbance, while maintaining key relationships among important system variables or populations (Holling 1973). Loss of resilience thereby would increase the necessity and the urgency for organisms to either adapt or disperse to avoid extirpation or extinction.

The increasing focus of conservation practitioners on coarser-scale targets—communities and ecosystems—(Groves 2003) further complicates strategies for protecting biodiversity when some of the dominant plant species that may define these systems become more mobile on the landscape. If defined on the basis of static composition, communities may become increasingly irrelevant as conservation targets, a perspective that is supported by considerable paleoecological evidence (Williams and Jackson 2007). The choice between managing to sustain a particular ecological assemblage in a given location or seeking other sites that may be more suitable for preserving key species and habitats under future climatic scenarios will be difficult. For example, fires in 2000 and 2007 almost extirpated big sagebrush (*Artemisia tridentata*) from tens of thousands of hectares of the shrub-steppe ecosystem at the Hanford Reach National Monument in eastern Washington. Furthermore, climate models suggest that the frequency and extent of fire in this region will increase. Managers must decide whether to struggle to reestablish the defining structural element of this ecosystem or to accept the current, largely shrubless, condition as a new management goal for burned areas, while seeking to protect shrub-dominated habitats in other areas that may be less fire-prone. In many cases, the solution may be to pursue both options. Over the short term, it may be worth attempting to manage and restore a particular system—to sustain key ecological processes and structural components—thereby allowing species to persist, while simultaneously taking actions that allow species to adapt or disperse, leading to the assembly of both similar and novel communities in other locations in response to changing climates.

Conservation Approaches

Our focus in this paper is on strategies for restoring and managing natural systems in light of likely changes in climate. In the following sections we describe three general categories that collectively embrace many of the approaches that The Nature Conservancy is applying, or has been considering, in Washington. We have described these categories under the terms component redundancy, functional redundancy, and increased connectivity (Table 1). The categories are by no means mutually exclusive, and the concepts frequently overlap as they are applied on the ground. However, they provide an organizational framework that is helpful in making mental linkages between how species and systems may respond to climate change and understanding how managers can incorporate these responses into management and restoration decisions. As we explored these approaches in a variety of contexts, we recognized that in many ways they were analogous to strategies that corporations use to make their products successful in the marketplace. Like most analogies, the corporate analogues are not perfect, but they provide a colorful and perhaps memorable means for thinking about these concepts.

Conservation practitioners work across a broad range of scales—from individual species and small habitat patches to entire landscapes. We contend that aspects of these three approaches are applicable at multiple scales, and so have chosen to illustrate each approach with two examples. The first explores the concept from the species level, and the second considers the approach from a broader community, site, or landscape perspective. In some cases these conservation approaches represent significant departures from past practices; in others, they are modifications of conventional practices in light of predicted changes in climate. Finally, it is critical to note that although most of our case studies describe actions taken within a management unit, future changes in climate will increasingly require managers to take a much broader perspective if they are to be successful. As the distribution of individual species expands or contracts, as novel assemblages of species develop across the landscape, and as the surrounding matrix of natural areas continues to change, decisions about what to conserve, restore, and manage will need to be made in light of the shifting—and often poorly understood—conditions in a highly dynamic context.

Component Redundancy: The Boeing Approach

Designers of complex systems, from modern commercial aircraft to wind farms, have recognized the value of incorporating component redundancy

Table 1. Relationship between three conservation approaches that land managers may undertake and possible responses of individual species to environmental disruptions. In many cases there is overlap and interactions among the table entries. Analogous actions as well as responses may also be inferred at the scale of communities and ecosystems.

	Component Redundancy (Boeing)	Functional Redundancy (Microsoft)	Increased Connectivity (Starbucks)
		ACTION	
	Increase number of individuals of local species	Introduce genotypes from other locales (or species with similar attributes as local species) and greater potential to adapt to future conditions	Conserve/restore areas essential to dispersal between populations or to new habitats
		CONSEQUENCE	
Persistence	Higher likelihood of survival due to increased population numbers	Higher genetic diversity increases likelihood of survival of individuals providing a particular function in changing conditions	Higher likelihood of survival of metapopulations due to increased pathways for dispersal and repopulation
Dispersal	With more populations established, higher likelihood of survival of species metapopulations	Distant taxa potentially suited to future climates introduced from outside their normal range of dispersal	Provide alternate pathways or means for movement
Adaptation	More individuals yield a higher likelihood that some will be able to adapt more quickly (increased genetic diversity)	Increased genetic diversity yields higher potential for successful adaptation of particular functional groups	Increase potential for inter-population breeding, heightening ability to adapt more quickly

into their products. Commercial aircraft generally have multiple engines, but are capable of continuing to fly even when some become inoperative. We suggest that an analogous approach, which we dub the Boeing approach, is useful for managing resilient ecological systems in the face of an uncertain future.

Perhaps the most widely recognized application of this idea in conservation biology is in metapopulation dynamics, where multiple populations of an organism occur across a landscape, providing redundancy that may enable the species to survive despite the occasional extirpation of a local population (Hanski and Gilpin 1997). An identical approach can be taken within a single site, in which the number of occurrences of individual species across a site can be increased to minimize the likelihood of stochastic extinctions. This approach, which may be manifest at the site level by an increase in alpha diversity, is an explicit strategy that may increase the resilience of communities in the face of climatic changes. Essentially, we see the Boeing approach as building resilience through the replication of pieces that already exist in a system. While others have previously suggested that species redundancy can enhance ecological resilience (Walker 1992, Naeem 1998), we suggest the concept has similar potential applicability at larger scales, such as with plant communities, and is immediately applicable in contemplating how to incorporate climatic change considerations into conservation, land management, and restoration.

At the scale of species and sites, we have begun to incorporate aspects of the Boeing approach into restoration activities in the small remnants of native prairies that persist in the Puget Lowlands of western Washington (Figure 1). In the past, the restoration emphasis at these sites has been directed primarily toward eradicating invasive species, reintroducing extirpated species, and reintroducing fire as a key ecological process. However, since much of the prairie plant diversity is represented by species with low densities or that occur in widely scattered groups, we are implementing a combination of adaptive approaches to enlarge the size and increase the density of small patches and subpopulations of many native species. Techniques include supplementing seed-limited native species using seed of local provenances, enhancing conditions for germination and establishment of native species through the use of fire and soil scarification, and reducing competition with invasive species via selective herbicide application. Furthermore, we are increasing the number of patch occurrences of many species across the prairie to provide greater redundancy of subpopulations. Rather than just ensuring that viable populations of rare species are established on the prairies, we are deliberately focusing on significantly increasing the species richness at small and medium scales while maintaining overall species richness (Figure 2). We hypothesize that this approach will significantly increase the persistence of many species and facilitate self-organization of restored communities, thereby increasing the long-term resilience of the sites to the challenges posed by future climate changes, and enhancing the ability of these systems to resist invasion by non-native species.

Figure 1. Native prairie remnants persist at low elevations throughout the Puget Lowlands of Washington and Oregon, despite the prolific growth of conifers in the surrounding forests. Photo by Peter Dunwiddie

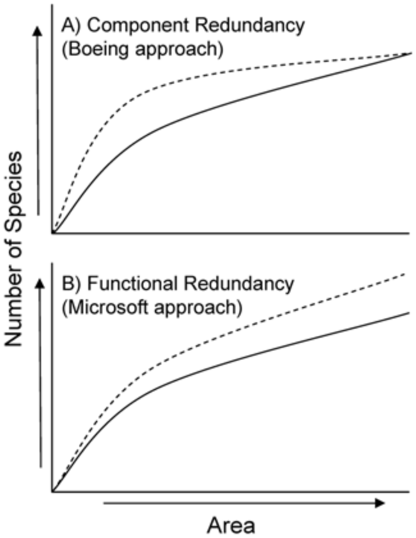

Figure 2. Graphical illustrations of the effect of conservation approaches on species-area curves. Solid and dashed lines represent the curves before and after an approach is employed: A) the component redundancy approach increases the rate at which species accumulate but does not affect the asymptote; and B) the functional redundancy approach introduces new species to a site, thus increasing the asymptote.

Following similar reasoning, conserving replicate examples of different communities, ecosystems, and habitats has been a fundamental precept of large-scale conservation planning and management for some time (Groves 2003). In many systems, structural diversity and complexity are developed and enhanced by disturbance processes that create mosaics of habitats. These mosaics may increase the likelihood for component species to persist and adapt. Similarly, when redundancy or complexity is reduced, systems are less resistant to disturbance, including those driven by climatic changes.

At the ecosystem level, we are incorporating some basic principles from the Boeing approach to increase system resilience at the Tieton River Canyon, located on the east slope of the Cascade Mountains (Figure 3). The site supports a mosaic of dry forests intermixed with shrub-steppe, arid grassland, and shallow soil habitat types (Franklin and Dyrness 1988). The dry forests historically occurred in a mosaic of structural states in response to the dynamics of a low- to mixed-severity fire regime, which is key to the system's biodiversity and resilience (Agee 1993). This patchy distribution across a large landscape provided for habitat recovery within the system's typical fire extent and rotation. The resistance and resilience of dry forest patches to fire is related to the landscape-scale distribution or redundancy of vegetation patches, to fuel loadings, and to diversity in patch age, structure and size. Past management practices, including fire exclusion, grazing, wildlife management, and timber harvest have homogenized forest structure within patches and increased patch size and connectivity (Hessburg et al. 2005). As a result, the risk of larger and more severe stand-replacing fires has increased. Many climate change models predict higher summer temperatures, suggesting that fire frequency, severity, and season length may increase. We hypothesize that increasing the structural and compositional heterogeneity of the landscape will increase the resilience of these dry forest systems. To accomplish this, we are manipulating stand structure and surface fuels in patches across the dry forest system using a combination of mechanical treatments and prescribed fire. Patches to be treated can be identified spatially to optimize fuel treatment effectiveness (Finney 2007). This will reduce the likelihood of large stand-replacing fires abruptly changing the system at a landscape scale, and instead facilitate a more gradual adaptation to the changing climatic environment (Agee and Lolley 2006). Over time, we believe the higher diversity and redundancy of stands and stand ages will result in a system more resilient to potential climate related changes in disturbance regime.

Functional Redundancy: The Microsoft Approach

A second general approach is exemplified by most popular computer software, where a particular task can be accomplished in multiple ways. For example, users can save a document by clicking on an icon, selecting a choice on a pull-down menu, or following a specified sequence of keystrokes. Ensuring a similar redundancy in ecological functions within a system may be a key to assuring the ability of managed ecosystems to adapt to climatic changes and remain viable for a broader diversity of organisms. This approach has many of the same strengths that component redundancy confers to the Boeing approach. However, rather than building resilience through the replication of pieces (e.g. species, communities) that already exist in a system, it incorporates redundancy through the replication of

Figure 3. The Tieton River Canyon includes a diversity of shrub-steppe, deciduous oak, and conifer-dominated forest habitats on the eastern slopes of the Cascade Range. Photo by Reese Lolley

novel components with similar functions. This replication can take place at many scales, from genotypes and species to communities and systems with similar structural attributes.

Within a community, following the Microsoft approach might lead to the introduction of functionally equivalent species to a site (Figure 2). In the short term, these species would augment the existing biota, but over time they could replace some species as climates change and conditions become unsuitable for some of the original biota. At the Ellsworth Creek Preserve in southwest Washington, we are restoring ecosystems that resemble the late-seral forests that once dominated the Northwest Coast Ecoregion. Unmanaged or late-seral rainforests in this region are composed primarily of western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*), with Douglas-fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) occurring in low abundance. Owing to the last century of management for timber production, planted, relatively even-aged stands of Douglas-fir and western hemlock now far outnumber naturally seeded western red cedar and Sitka spruce. The question is how to restore both the composition and structure of these forests to healthy conditions in the face of global climate change. The challenge is particularly difficult, considering the typical longevity of the dominant trees; most of these species are long-lived, with individuals reaching ages of 400–800 years or more. Rather than attempt to replicate the composition of historic forests, we have decided to promote the development of forests with similar structure and function.

While wind disturbance has historically been a major driver of forest development in these forests, fire could become a more frequent disturbance in response to projected warmer, drier climates in the future. Therefore, we are retaining Douglas-fir as a prominent component in restored forest stands, since it is both resistant and resilient to fire and is a dominant species within fire-adapted landscapes to the south and in interior regions of the Pacific Northwest (Agee 1993). In addition, over the long-term, we also may consider introducing another fire adapted species, coast redwood (*Sequoia sempervirens*), to the preserve. This species today naturally occurs in coastal forests several hundred kilometers south of Ellsworth Creek, but both redwoods and Douglas-firs may be well suited to anticipated future climatic conditions. The trees may offer functional redundancy by providing structural features that replicate important attributes of native forests, such as canopy platforms for nesting marbled murrelets (*Brachyramphus marmoratus*) and the development of epiphytic vegetation, similar microclimate regimes, and sources for instream and forest-floor large woody debris. The forests that develop as these species mature may be better adapted to future conditions and could, in turn, sustain many other components of the forest system under future climate scenarios.

At the ecosystem scale the Microsoft approach might lead conservation practitioners to consider introducing suites of species that are functionally similar to existing biota but may be better suited to future climates. One example is afforded by lands enrolled in the Conservation Reserve Program (CRP) in eastern Washington. This federally funded program reimburses farmers for converting environmentally sensitive agricultural lands to permanent vegetative cover. While the use of native species is increasingly encouraged, functionally similar non-native species, as well as nonlocal genotypes, are widely incorporated. CRP does not support the diversity of biota that native communities provide. However, these fields replicate structural and functional elements critical to species of concern such as the greater sage grouse (*Centrocercus urophasianus*, Schroeder and Vander Haegen 2006).

Approximately 650,000 ha are currently enrolled in CRP in eastern Washington (Farm Service Agency 2009). If a high proportion of this acreage were to be converted back to agriculture, the viability of native birds and other wildlife would be significantly negatively affected (Schroeder and Vander Haegen 2006). Ensuring that CRP lands remain in permanent vegetation cover is an important strategy that we are implementing to conserve biodiversity in the Moses Coulee Conservation Area in north-central Washington. Clearly, it would be detrimental to native biodiversity if the creation of CRP habitats came at the expense of native habitat. However, this strategy is only pursued on lands already converted to agriculture, and is carried out in combination with other strategies to protect and restore native shrub steppe lands.

In the past, this strategy has been opportunistic or focused on CRP fields adjacent to shrub-steppe systems. Consideration of climate change impacts adds a different criterion for selecting priority areas: parcels that provide connections between native shrub steppe patches, even if surrounded by cropland, become increasingly important as corridors for species dispersing in response to climate change. In addition, we encourage researchers to take advantage of this extensive, real-world laboratory to study the responses of both non-native species and nonlocal native genotypes to changes in climate that have already occurred. Such information is vital to identify CRP lands most likely to provide functional redundancy under expected climates, and to inform future revegetation programs.

From a conservation perspective, the Microsoft approach might be regarded as more long term than the Boeing approach. Whereas the latter seeks to sustain species and communities in or near sites where they currently exist, the Microsoft approach takes a broader view that allows greater flexibility and latitude in developing and conserving novel species assemblages and in moving organisms across the landscape. Such an approach raises difficult questions about which species are considered "native" or how conservation goals and objectives should be defined during a time of rapid climate change. This approach also presents significant challenges for managers seeking to identify not only which ecological functions are critical within a system, but which species or assemblages may offer functional equivalency. Nevertheless, such approaches may become more central to conservation practitioners in coming decades, and should be the subject of research and discussion now.

Increased Connectivity: The Starbucks Approach

Seattleites joke that you are never out of sight of a Starbucks coffee shop. Keeping coffee connoisseurs within easy range of their next cup makes good business sense, and the same concept applies to the conservation of natural systems. Ensuring that organisms are able to move about and that key ecological processes can take place, with few barriers imposed by borders, fences, and lines of ownership, are fundamental precepts of conservation area design. There is a large body of literature that discusses the importance of managing for functional connectivity, from building salamander tunnels and wildlife overpasses across highways, to sustaining ecological processes across intervening landscapes (Crooks and Sanjayan 2006, Lindenmayer and Fischer 2006). The challenge is to make connectivity truly functional across the diversity of scales at which conservation actions occur (Harris et al. 2006).

At the species level, corridors, landscape linkages, wildlife passages, and other connectors may allow movement of some organisms. Consider, for example, the challenges faced by anadromous salmon in the western United States. About half of the extant populations of the six major Pacific salmon species (*Oncorhynchus* spp.) are listed as federally threatened or endangered (Gustafson et al. 2007). While degraded habitat, hydrological alteration of stream systems (e.g., dams), overfishing, and the management of hatcheries are often mentioned as the major threats to salmon, climate change is becoming a significant concern (e.g., Shared Strategy for Puget Sound 2007). Models predict that mountain snowpacks will decrease and spring runoff will occur earlier in many rivers throughout the Pacific Northwest (Milly et al. 2005). These changes, combined with increased winter rains and possible decreases in summer rains, could also create higher winter stream flows with more flood events, and lower summer stream flows (USCCSP 2008). These changes will have significant effects on the distribution, timing of spawning and outmigration, and ultimate survival of Pacific salmon.

In Washington, our conservation planning for freshwater systems and salmon incorporates the Starbucks approach toward enhancing dispersal and migration opportunities in functionally connected habitats. First and foremost, we are looking at conservation at the scale of whole watersheds and associated marinescapes—from the summit to the sea. By doing this, we are able to develop conservation strategies that focus on the connectivity of habitat and processes throughout a watershed. Salmon require multiple habitats as they progress through their life cycle (e.g., gravels for spawning, pools and side channels for rearing and overwintering, estuaries and shorelines for rearing), and conservation or restoration of each of these linked habitats is critical for their survival. Moreover, with changes in climate and an expected increase in disturbance frequency and intensity from floods and landslides, the conservation of multiple zones of functional habitat in tributary basins throughout a watershed may provide important refugia for salmon as habitat recovers. Finally, the location of conservation and restoration projects in a watershed is important: higher-elevation sites are more likely to transition from snow- to rain-driven hydrology as temperatures rise, suggesting that lower-elevation projects could be more successful (Battin et al. 2007)

However, green lines on a map or proximity of nature preserves are no guarantee that biota as diverse as wolves, butterflies, slugs, lupines, and lichens can actually disperse from one

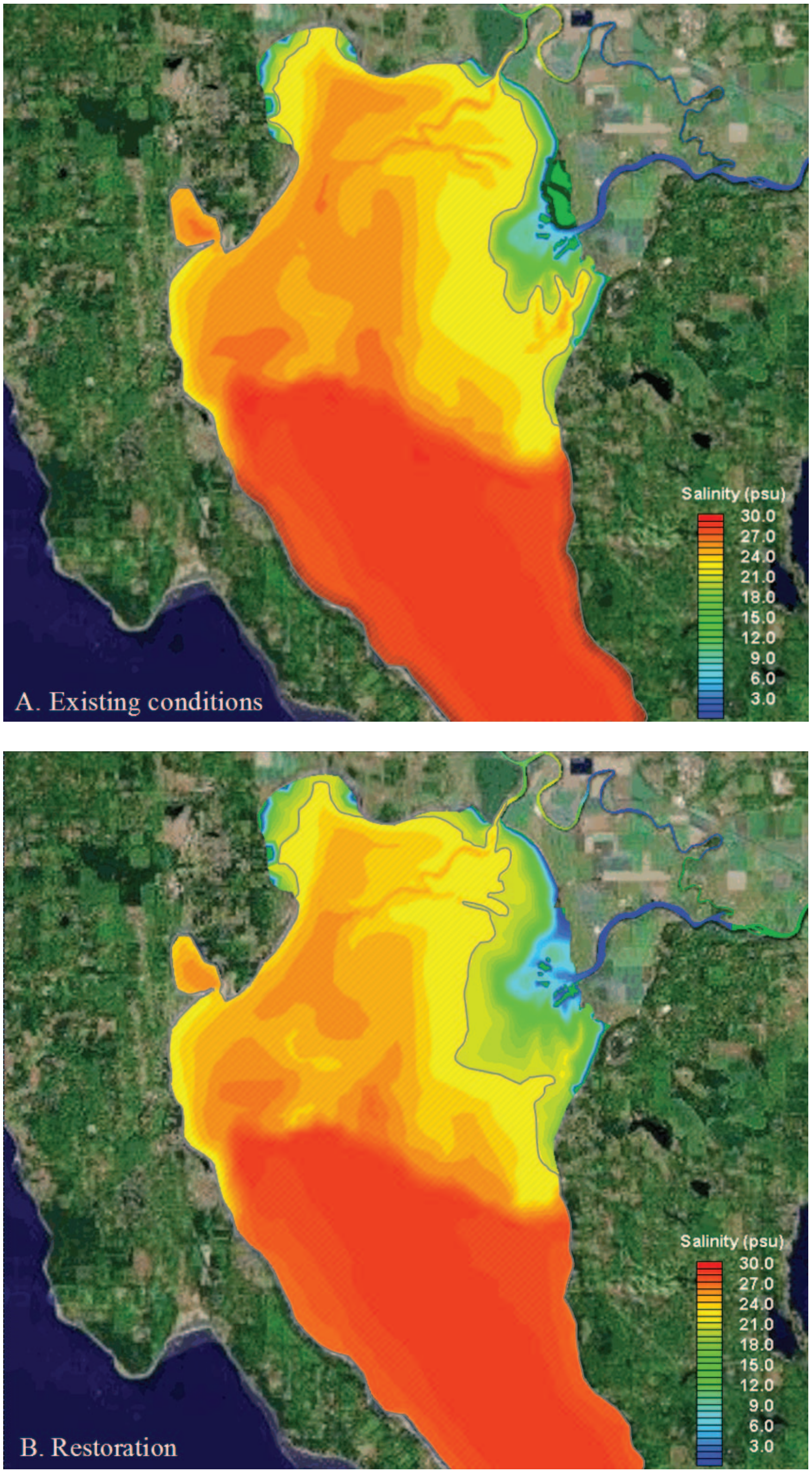

Figure 4. Modeled salinity distribution at flood tide in Port Susan Bay, Washington, A) under existing conditions and B) with proposed restoration of 60 ha at the mouth of the Stillaguamish River. The hatched area (lighter, yellow and orange areas) indicates where salinity exceeds 21 psu, which is near the upper tolerance limit for most estuarine vegetation. Note the larger plume of lower salinity water in the upper right of B). Modeling by Battelle Pacific Northwest National Laboratory

preserve to another. Challenges arising as a result of climate changes will be further compounded by continuing habitat fragmentation and a decline in quality and functionality of the intervening matrix habitats. Ensuring that organisms can continue to move into more suitable habitats is a growing challenge (Opdam and Wascher 2004).

These difficulties in maintaining, restoring, or mimicking ecological connectivity are even more problematic at the large scales that often are necessary to ensure functionality of ecological processes. Conservation actions are increasingly taking place at these larger scales, a trend driven in part by the recognition that elevational and latitudinal gradients contribute valuable flexibility in conservation designs. Plans such as "Yellowstone to Yukon" and "Baja to Bering" (Morgan et al. 2005) not only offer greater opportunities for preserving wide-ranging species and ecological processes that operate at large scales, but also protect a greater diversity of habitats, thereby providing more opportunities for dispersal into suitable habitats.

The Starbucks approach can also be applied at intermediate scales that focus on ecosystems and the ecological processes that sustain them. In Washington, we are applying it to an estuarine ecosystem in Port Susan Bay to restore connectivity and improve the system's ability to adapt to long-term changes in both climate and basin land-use patterns. In estuaries, a few key ecological factors and their spatial distribution drive the development and area of habitats, the ecosystem services they supply, and their adaptability to change: salinity, sediment dynamics, and inundation levels (Morris et al. 2002, Spalding and Hester 2007, Craft et al. 2009). All of these are influenced by climate change (Day et al. 2008).

Port Susan Bay has been highly modified by decades of diking and conversion of estuarine floodplains. These actions resulted directly in habitat loss, but perhaps just as importantly, they altered the controlling factors for the remaining estuarine habitat by changing hydraulics and the distribution of freshwater and sediment (Hood 2004). As a result, the condition and resilience of the estuarine ecosystem has been impacted at a spatial and temporal scale larger than the footprint of diked lands.

Restoration efforts generally take an opportunistic approach to removing dikes and restoring habitats whenever or wherever a parcel becomes available. The problem with this approach is that, like the initial diking action itself, it ignores the spatial and temporal context of the parcel with respect to the estuarine ecosystem. In the short term, any estuary restoration project is likely to deliver valuable habitat for biota of interest. However, when considered in the larger spatial and temporal context, a project could either increase long-term resilience of the system or accelerate its trajectory toward an undesirable state change. For example, modeling results suggest that removal of a sea dike at the mouth of the Stillaguamish River could increase freshwater residence time in the estuary (Figure 4). This might increase resistance to the salinity intrusion imposed by sea level rise, and thereby increase the functional resilience of freshwater tidal habitats. In contrast, a mid-delta project, removing a sea dike in an area where riverine connectivity has not yet been restored, might accelerate salinity intrusion and trigger the loss of existing tidal marshes. In the latter case, productive salmon-rearing habitat would be restored in the short term but, despite the best intentions, the project could accelerate habitat loss in the face of sea level rise in the long term. The question is not *whether* to restore the mid-delta site, but *when*, and the answer depends on first restoring connectivity with the river to ensure the processes are present that will sustain the site in the face of climate change.

Though resilient ecosystems are often an implicit objective of restoration, resilience is a characteristic of larger spatial and temporal scales than restorationists generally consider. Traditionally, explicit project objectives have been structural, such as habitat acreage targets, and they occasionally address processes such as restored hydrology. However, rates of change in sea level and other coastal climate change impacts demand that our focus evolve quickly to encompass resilience as an explicit and primary objective of restoration. If resilience is not an explicit goal, it may not be achieved, and this failure could go undetected by monitoring efforts, potentially leading to significant surprises and ineffective use of resources.

The pace of climate change requires that we act quickly, despite considerable levels of uncertainty regarding how estuarine habitats and species will respond. An ecosystem-scale adaptive management program with a rigorous long-term monitoring system allows managers to take action now and adapt management as lessons are learned. To understand how projects are affecting ecosystem resilience, monitoring must be focused on resilience indicators, rather than short-term structural outcomes such as acres restored or number of fish present. For example, measures of estuary resilience could include temporal and spatial trends in sediment capture, freshwater distribution, organic accretion, root/shoot ratios, and landscape-scale habitat diversity and complexity. Restoration projects should be planned, designed, and monitored with respect to how they affect ecosystem-scale measures. Proceeding with estuarine conservation without the appropriate spatial and temporal perspective on ecological processes could reduce system resilience to climate change despite our best intentions.

Risks

None of the strategies described in this paper are without risk. Clearly, the complexities of natural systems generally far exceed our current abilities to understand them; unexpected outcomes and unanticipated consequences seem more the rule than the exception. It would be the epitome of hubris to think that we could fully understand how a species would behave when introduced into a system where it currently does not exist, under conditions that are not yet precisely known. Similarly, there currently is little guidance for how communities and ecosystems should be created, restored, and managed in a thoughtful and responsible manner that anticipates the development of future assemblages with no contemporary analogs. But it would be equally fallacious to adhere blindly to a rigid creed of historic condition and precedent, and fail to recognize that a new world of altered climates and novel assemblages of species is hard upon us (Seastedt et al. 2008). To successfully meet these challenges necessitates the continual development and adaptation of new conservation strategies.

The nature, magnitude, and likelihood of negative consequences that may ensue by pursuing approaches such as we have outlined are, in many cases, difficult to gauge. Discussions of our restoration efforts in Washington with both conservation practitioners and researchers have highlighted several potential risks of the different conservation approaches we have described in this paper (Table 2). For example, approaches that significantly change the composition or relative abundance of species, such as discussed in the Puget lowland prairies and Ellsworth Creek case studies, are likely to disrupt the balance among species currently occupying the site, and result in altered interactions among the plants, animals, and ecological processes. Some of these changes may enhance the survival of desired species, but others may be difficult to anticipate and may have negative consequences. Management activities that facilitate movement of organisms within or among sites, a likely outcome in several of the case studies, could be a two-edged sword as

Table 2. Some potential risks of the proposed conservation approaches.

	Component redundancy (Boeing)	Functional redundancy (Microsoft)	Increased connectivity (Starbucks)
Disrupt balance among species of differing abundance and life history	X	—	—
Unanticipated species interactions	X	X	X
Greater homogenization of species assemblages	X	—	X
Dilution or loss of locally adapted genotypes	X	—	X
Easier movement of pathogens, predators, and invasive species	X	—	X
Alteration of ecosystem processes	X	X	X
Creation of novel communities and ecosystems	—	X	X

well. Metapopulation dynamics may be enhanced and native species may be better able to move to more suitable sites as climates change, but local genotypes may be compromised, species assemblages may become increasingly homogenized, and pathogens and invasive species may more readily move about. The novel communities, ecosystems, and ecological processes that develop in the future will inevitably create conditions favorable to some desired species but deleterious to others.

These examples are by no means exhaustive; undoubtedly other risks exist as well, and many of the issues become even more complicated and uncertain when they are applied at larger scales and begin to involve multiple management units. However, it is important to anticipate some of these consequences in order to develop both adequate monitoring to detect their possible occurrence and impact and alternative strategies that may mitigate them.

Conclusion

There are no easy answers to questions about whether and how to assist native species, communities, and ecosystems to persist, adapt, disperse, or reassemble themselves elsewhere. Nor are there many obvious, no-risk strategies for successfully conserving and restoring biodiversity in a changing world. The difficulties in developing responsible and effective strategies are well illustrated by the debate that has sprung up around the issue of assisted migration (McLachlan et al. 2007, Mueller and Hellman 2008). In many areas, fragmentation is so advanced that restoring true functional connectivity may be precluded, and alternative strategies, such as assisting organisms to move to other sites, perhaps even where they may not have previously existed, are being considered. This is an issue that will require careful consideration from a variety of perspectives, including ecological, genetic, economic, and sociological. Assisted migration and many of the other possible strategies for mitigating effects of climate change that have been proposed in this paper need to be approached using well-designed experiments, careful documentation and monitoring, and a flexible, adaptive approach that maximizes the potential for learning opportunities.

Precisely because some of the ideas posed in this paper run against the flow of widespread conservation practices, we hope that conservation biologists, restorationists, and other practitioners will be encouraged to examine them closely, identify both the potential benefits and the risks of adopting them, develop experiments to test their effectiveness, explore ways that can reduce some of the risks, and continue to seek management and restoration strategies that will help ensure the preservation of species for future generations.

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