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Managing for RADical ecosystem change: applying the Resist-Accept-Direct (RAD) framework

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Ecosystem transformation involves the emergence of persistent ecological or social–ecological systems that diverge, dramatically and irreversibly, from prior ecosystem structure and function. Such transformations are occurring at increasing rates across the planet in response to changes in climate, land use, and other factors. Consequently, a dynamic view of ecosystem processes that accommodates rapid, irreversible change will be critical for effectively conserving fish, wildlife, and other natural resources, and maintaining ecosystem services. However, managing ecosystems toward states with novel structure and function is an inherently unpredictable and difficult task. Managers navigating ecosystem transformation can benefit from considering broader objectives, beyond a traditional focus on *resisting* ecosystem change, by also considering whether *accepting* inevitable change or *directing* it along some desirable pathway is more feasible (that is, practical and appropriate) under some circumstances (the RAD framework). By explicitly acknowledging transformation and implementing an iterative RAD approach, natural resource managers can be deliberate and strategic in addressing profound ecosystem change.

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Contemporary ecosystem change driven by a suite of global anthropogenic stressors has had reverberating consequences across genetic, population, community, and ecoregional scales (Díaz *et al.* 2019). Fine-scale changes in phenology, morphology, abundance, gene frequencies, and distribution of populations and species (eg Staudinger *et al.* 2013) can scale up to system-level conversions and biome shifts (Scheffer *et al.* 2009). Often driven by changing climate, many of these changes are manifest in ecological and physical stresses, including invasive-plant incursions, drought, desertification, severe fire, pest outbreaks, and geographic displacement of species. Extreme ecosystem changes are occurring with increasing frequency across a range of biomes, including coral bleaching in the tropics and grassification of shrublands (Figure 1). Ecosystem changes are expected to continue across many biomes even under scenarios with aggressive reductions in greenhouse-gas emissions, with globally distributed and radical ecosystem alterations predicted under high-emission scenarios (Nolan *et al.* 2018; Reid *et al.* 2018).

In a nutshell:

- Ecosystem transformations represent the emergence of new ecological states that diverge dramatically from prior structure and function
- Such transformations are occurring at unprecedented rates and spatial extents because of global pressures, such as climate change, habitat conversion, harvest, pollution, and invasive species
- Management under ecosystem transformation can consider multiple strategies to *resist*, *accept*, or *direct* trajectories of ecosystem change
- Guiding principles exemplified by existing management cases provide context for management decisions in the face of ecosystem transformation

We define these intensive and comprehensive system changes as ecosystem transformation (ie the emergence of a self-organizing, self-sustaining ecological or socioecological system that diverges considerably and irreversibly from prior historical ecosystem structure, composition, and function; Noss 1990). Transformations include ecosystem disruptions (eg Embrey *et al.* 2012) and occur across a range of temporal scales – for instance, from single-event high-intensity fires (Guiterman *et al.* 2018) to glacial–interglacial transitions spanning many millennia (Nolan *et al.* 2018) – and range widely in spatial extent, from a local community to entire biomes (Thompson *et al.* 2021). These changes pose critical threats to ecosystem services and consequently to human health and well-being, clean air and water, food security, sanitation, and disease mitigation (Whitmee *et al.* 2015).

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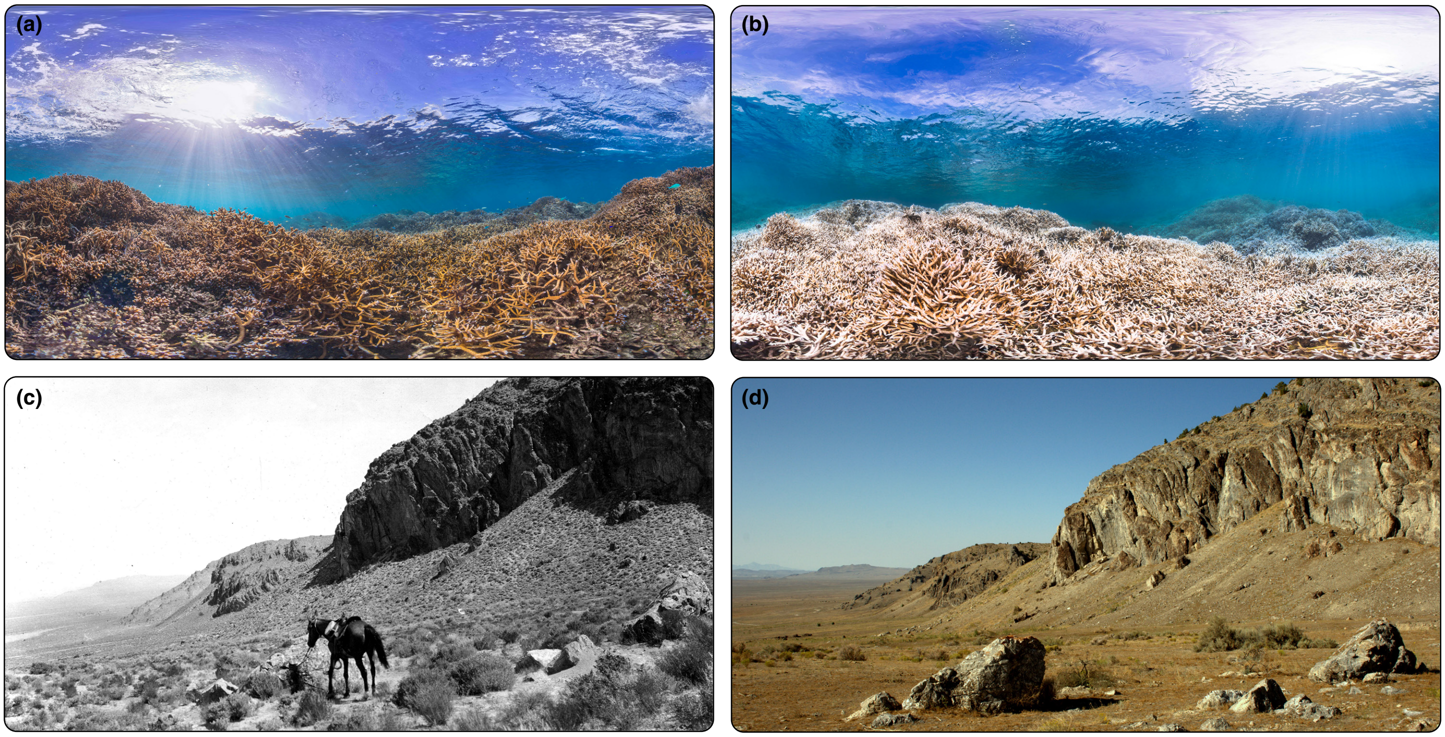

The Ocean Agency/XL Catlin Seaview Survey 2014

The Ocean Agency/XL Catlin Seaview Survey 2015

USGS, Denver Library Photographic Collection (1901)

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Figure 1. Coral bleaching: (a) coral reef systems, such as this one in American Samoa, are home to a quarter of all marine biodiversity, but rising ocean temperatures and ocean acidification are causing (b) mass bleaching events, which have a ripple effect through the reef communities and impacts on biodiversity and other important ecosystem services such as tourism and fishing. Grassification: (c) shrublands in the Great Basin of North America are important habitat for small mammal communities, such as here at the base of the Cedar Mountains 50 km from Homestead Cave; (d) recent grassification of this habitat with the fire-induced invasion of cheatgrass (*Bromus tectorum*) and other annuals has had profound impacts on energy flow in small mammal communities. Compared to a baseline spanning the entire Holocene, energy flow has declined markedly over the past 100 years, with a shift toward small body size species, particularly granivores associated with closed grass habitats, without compensation from the other body size, diet, or habitat classes (Terry and Rowe 2015).

Here, we outline management challenges associated with ecosystem transformation and identify decision pathways that allow managers to *resist*, *accept*, or *direct* trajectories of change. Using recent examples, we argue that iterative learning, with specific tailoring for *resist*, *accept*, or *direct* (RAD) strategies, provides a foundation for thoughtfully managing ecosystem transformation. We conclude with a set of guideposts for managers who wish to transition toward a portfolio of RAD strategies to address ecosystem transformation. We intend that these guiding principles serve as a base for broader discussion about managing ecosystem transformation.

Management approaches for ecosystem transformation

Effectively managing ecosystem transformation requires a holistic framework that acknowledges all potential response options, preferably those readily incorporated into existing climate-informed management schemes (eg Stein *et al.* 2014). The Resist-Accept-Direct (RAD) framework encompasses management options that range from *resisting* change to *directing* the trajectory of change (Fisichelli *et al.* 2016; NPS 2020; Thompson *et al.* 2021; also see NPS 2016). Building on previous efforts to address persistent directional change (eg "resist-accept-guide" of Aplet and Cole [2010]), the RAD framework addresses two emerging management needs arising under ecosystem transformation (Hobbs *et al.* 2014; Aplet and McKinley 2017): to think beyond resistance (Millar *et al.* 2007) and to influence trajectories of change (Aplet and Cole 2010; Hobbs *et al.* 2011). Formalization and adoption of the RAD framework by the Federal Navigating Ecological Transformation working group (FedNET; see acknowledgements section) reflects a growing consensus that managers can apply any of three approaches to address ecosystem transformation that results from a changing climate or other directional drivers of change:

(1) *Resist* ecosystem transformations; management actions focus on maintaining current or historical ecosystem structure and function (services);
(2) *Accept* ecosystem transformations; managers yield to ongoing transformations (ie by not intervening), accepting ecosystem structure and function that emerge from the transformation; and
(3) *Direct* ecosystem transformation toward a specific alternative outcome; managers accept that change is inevitable but intervene to steer the transformation toward an ecosystem state with particular structure and function.

Each option in the RAD trichotomy represents trade-offs among management goals, societal values, and available resources, based on the rates and magnitudes of the natural forces underlying transformation. Ideal outcomes might be self-sustaining and self-organizing (therefore requiring minimal future intervention), but subsequent environmental change or newly arrived species might require a new round of RAD decisions.

Choosing an appropriate approach

Systematically exploring the full range of contrasting RAD management options allows for comparison among potential ecosystem outcomes when responding to transformation. Rather than asking which actions will produce the single best outcome, it may be preferable to ask which actions will provide the best chances of acceptable outcomes (Stein *et al.* 2014). Often, this process must begin by acknowledging uncertainty in the science of ecosystem transformation and then committing to approaches most robust to that uncertainty (Ingeman *et al.* 2019). This may involve applying multiple RAD strategies concurrently (eg *resist* transformation in one part of a landscape while *accepting* or *directing* it in another) or sequentially as a bet-hedging approach that implements short-term strategies to maintain management flexibility for uncertain changes over the long term (eg *resist* change initially to buy time for longer term efforts that *direct* to a new state).

Each ecosystem transformation is context-specific; savanna encroachment into grasslands, for example, requires a different response than increased alpine glacial melt (Figure 2). However, three broad feasibility criteria – ecological, societal, and financial – must be considered when deciding which RAD strategy is practical and appropriate. Ecological feasibility reflects whether a given RAD strategy can be successfully implemented within the biophysical constraints governing composition, structure, and function of a managed ecosystem. Societal feasibility reflects whether RAD strategies can be implemented given cultural norms, systems for valuing ecosystems and their services, and regulatory or policy constraints. In many cases, management actions under ecosystem transformation may require overcoming inertia from some factions of society, including local (cultural) traditions, legal entitlements to ecosystem services, existing regulations, or agency culture. Successful implementation in such situations can be achieved through education about potential benefits and risks of a proposed strategy relative to feasible alternatives, and management decisions may need to be taken without absolute consensus because of irreconcilable objectives across stakeholder groups. Legal requirements are often markedly difficult to navigate in the RAD decision space because legal judgments and consent decrees often prescribe *resistance* (through a focus on historical conditions). Finally, financial feasibility entails whether monetary and related resources are sufficient to enact and sustain a given RAD strategy.

We posit these criteria as a useful framing context but acknowledge the risk of oversimplifying complex, nonlinear, synergistic dynamics. Although ecological, societal, and financial feasibility criteria may be considered binary (ie feasible or not feasible), in reality, each reflects a gradient of constraints (eg proposed costs can be more or less acceptable; spatial extent and timescales can be adjusted to enhance ecological practicality of actions). Overly precise targets can limit future flexibility and may cause unintended harm (Hiers *et al.* 2016). Lastly, these criteria are also often interdependent (eg financial feasibility may be a corollary of societal feasibility) and context-specific (eg financial feasibility may vary among agencies and political administrations, societal feasibility may vary among locales and their cultural histories).

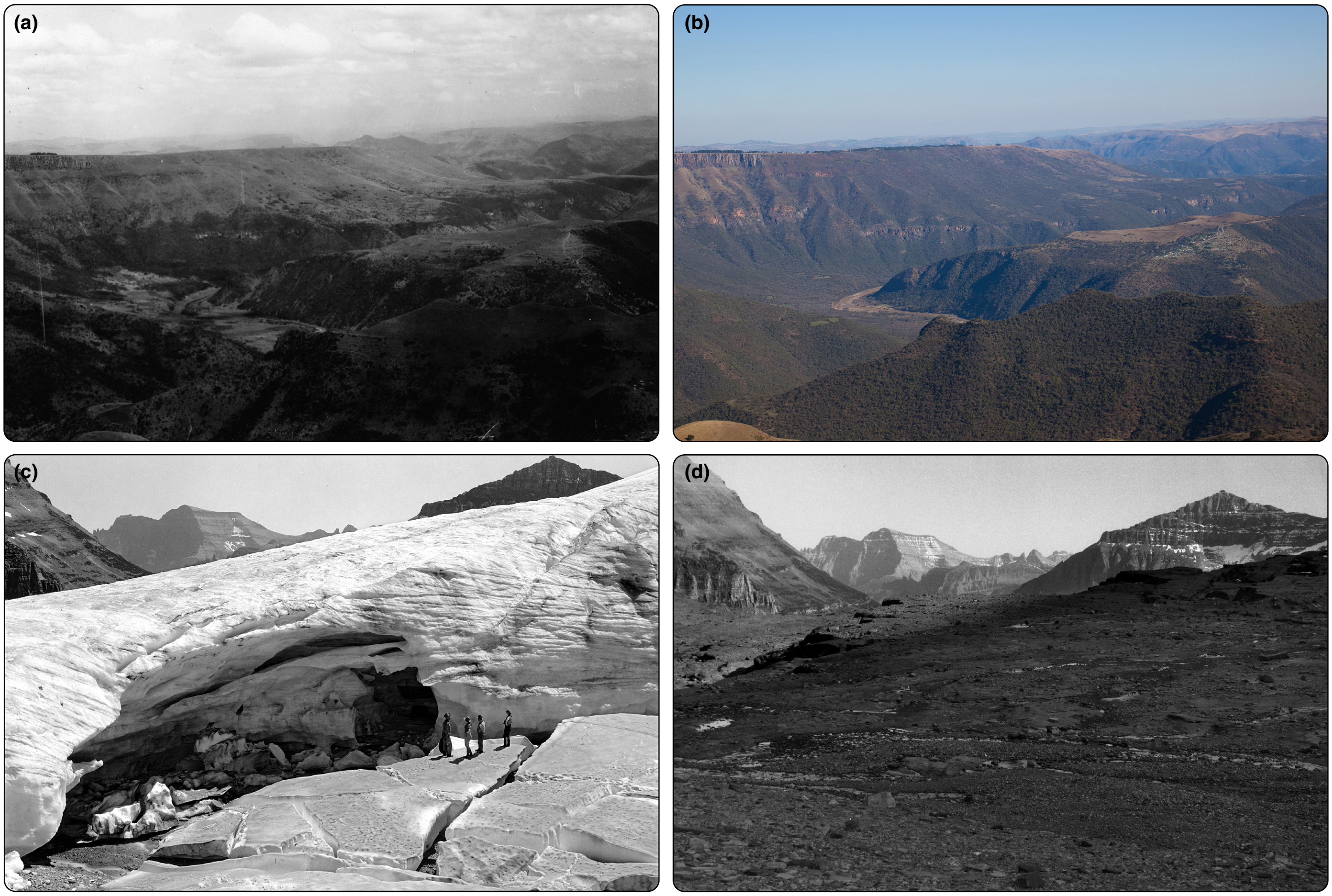
Ideally, RAD decisions will meet all three feasibility criteria. In some cases, multiple options will exist in the optimum solution space; in many more cases, however, none will. Management actions that meet only one of the criteria are also likely to be nonstarters. But when decisions satisfy only two of the three criteria, managers may have the opportunity to alter ecological, societal, or financial constraints to achieve feasibility for some RAD strategies.

Ultimately, it is a matter of practicality

Strategies can be ecologically and societally feasible but financially impracticable. For instance, propagation and outplanting can mitigate the loss of corals caused by rising sea temperatures, diseases, and catastrophic storms. These actions are costly, typically exceeding available resources when implemented at scales needed to effectively *resist* loss of reef ecosystems. But emerging conservation finance approaches are greatly reducing financial burdens of coral restoration. For instance, the Mexican state of Quintana Roo, The Nature Conservancy (TNC), and local stakeholders partnered to establish a fund (from beachfront property fees) for coral restocking after major storms (see Einhorn and Flavelle 2020) along with citizen-science programs like "Rescue a Reef", where self-funded expert divers outplant *Acropora* coral (Hesley *et al.* 2017).

Strategies can be ecologically and financially feasible but meet with societal reluctance from some groups. A spruce bark beetle (*Dendroctonus rufipennis*) epidemic and wildfires, as an example, have shifted white spruce (*Picea glauca*) forests on Alaska's Kenai Peninsula into novel grasslands (Bowser *et al.* 2017). Managers are considering *directing* change by introducing wood bison (*Bison bison athabascae*) or other large grazers to promote a more age- and species-diverse grassland, but this proposition may be hindered by federal legislation (Olson 2015).

Strategies can be societally and financially feasible but ecologically problematic, particularly in urban landscapes (Bettencourt and West 2010). Carter Lake, an oxbow of the Missouri River in metropolitan Omaha, Nebraska, has evolved from a lake dominated by recreational uses (eg powerboating, hatchery-sustained fishing) that were incompatible with aquatic ecosystem integrity to a lake that now features natural aesthetics and improved water quality. However, this system is ecologically unstable given the urban context in which the lake is situated and ongoing global change (eg lake warming, species introductions). This *directed* change will therefore require continued extensive management



A du Toit; CC BY-NC 4.0 (1922)

J Puttick; CC BY-NC 4.0 (2011)

G Grant/Glacier NP Archives (Boulder Glacier 1932)

J DeSanto/K Ross Toole Archives, U Montana (Boulder Glacier 1988)

Figure 2. Savanna encroachment: (a) grasslands in South Africa have high species richness and play important roles in water production. (b) As a result of climatic changes, the altitudinal limit of savannas is increasing and they are spreading into South African grasslands. Consequently, grasslands are one of the most threatened biomes in South Africa (both images courtesy of T Hoffman and copyright of the Plant Conservation Unit [UCT] under a CC BY-NC 4.0 Creative Commons license). Glacial melt: (c) glaciers and mountain snowpack are important for recreation, agriculture, and hydropower, as well as ecological function. (d) As glaciers retreat and mountain snowpack is lost, implications can be substantial for loss of these important services. For example, the meltwater stonefly (*Lednia tumana*) has been listed under the US Endangered Species Act as one ecological consequence of glacier melt.

intervention to maintain in the long run, and may ultimately include *resisting* and *accepting* actions as well.

Although deciding among RAD strategies is a difficult task, a number of operational tools are available to facilitate a deliberative RAD approach to managing ecosystems. Rapid prototyping and scenario planning can catalyze stakeholder dialogue to clarify management priorities (Blomquist *et al*. 2010) and identify the ecosystem-transformation management outcomes that are acceptable to stakeholders. Subsequently, cost–benefit analyses can help select the most appropriate outcomes, given existing constraints on management resources. In this regard, ecosystem valuations will be critical for quantifying the potential costs and benefits (Turner *et al*. 2010) of different RAD options, including characterizing the potential cost of the default option of *accepting* transformations.

In many cases, practically speaking, *accepting* ecosystem transformation will be the only financially feasible option; in others, no solution may emerge. The decision space is not static, however, and the optimum solution is a shifting target: what constitutes a feasible option at one time may not be so in the future. For example, the Minnesota Department of Natural Resources manages many lakes that currently support commercially and recreationally important coldwater cisco (*Coregonus artedi*). Managers are *resisting* change by pursuing conservation easements and other land-protection mechanisms for lakes that are projected to support cisco even under warming conditions; in lakes where cisco are unlikely to persist into the future, the agency has *accepted* that the trophic structure of and subsequent services provided by these lakes will inevitably change (Jacobson *et al.* 2013).

National Wildlife Refuge responses to ecosystem transformation

Although few management agencies or units have adopted an explicit RAD decision process, all three choices are being applied at various locales. Here, we discuss three case studies north of Cape Hatteras along the East Coast of North America, a sea-level-rise (SLR) hotspot where sea level is increasing at three to four times the global average rate (1.9 ± 0.4 mm yr^{-1}; Church and White 2011). Salt marsh habitats occur at elevations ≤0.6 m above mean sea level, and as such even small increases in sea level can trigger local ecosystem transformation. John H Chafee, Chincoteague, and Blackwater National Wildlife Refuges (NWRs), all managed by the US Fish and Wildlife Service (FWS), lie within this SLR hotspot (Figure 3). These refuges, established for the same primary purpose (wintering migratory waterfowl), are responding differently to the ecological consequences of SLR (Table 1).

John H Chafee NWR

Managers at the John H Chafee NWR, a 220-ha reserve in coastal Rhode Island, chose to *resist* SLR effects by depositing thin sediment layers to maintain salt marsh in situ. Waterlogging of the marsh surface has transformed salt marsh to unvegetated pans and mud flats, and options for upslope marsh migration are lacking due to topographical constraints and surrounding rural and urbanizing landscapes. The refuge partnered with the State of Rhode Island and TNC on a \$1.4 million project focused on maintaining 12 ha of salt marsh in the Narrow River estuary. In 2018, crews dredged over 500 m^3 of sediment within designated areas in the river and deposited the dredged material on the existing salt marsh, elevating its surface by ≥15 cm. The foundation of the new marsh is being held in place by ~1500 bags of recycled clamshells that are expected to be colonized by plants and invertebrates. In addition, as part of its *resistance* strategy, the refuge and its partners will replant sections of the restoration area, with full revegetation of the marsh expected to take 2–5 years.

Chincoteague NWR

The Chincoteague NWR occupies 5,600 ha at the south end of Assateague Island, a 60-km-long barrier island on the Virginia coast co-managed by the FWS and the US National Park Service (NPS). The two agencies, working closely with the Town of Chincoteague, recently chose to *accept* island migration and dune overwash as a strategic retreat from rising seas. After six decades of aggressive maintenance of an artificial dune, a series of severe storms and accompanying expenses rendered *resistance* to SLR and longshore currents economically infeasible. *Acceptance* included the conscious choice by refuge managers to allow two waterfowl impoundments to fill in and to permit the frequent overwash of a third by seawater, which is dramatically transforming the landscape. *Acceptance* also necessitated moving and rebuilding NPS visitor service infrastructure, a form of active management but not intervention to influence the transformation trajectory. Managers have chosen to *resist* transformation elsewhere in the refuge, however, by installing artificial oyster reefs to reduce bayside erosion.

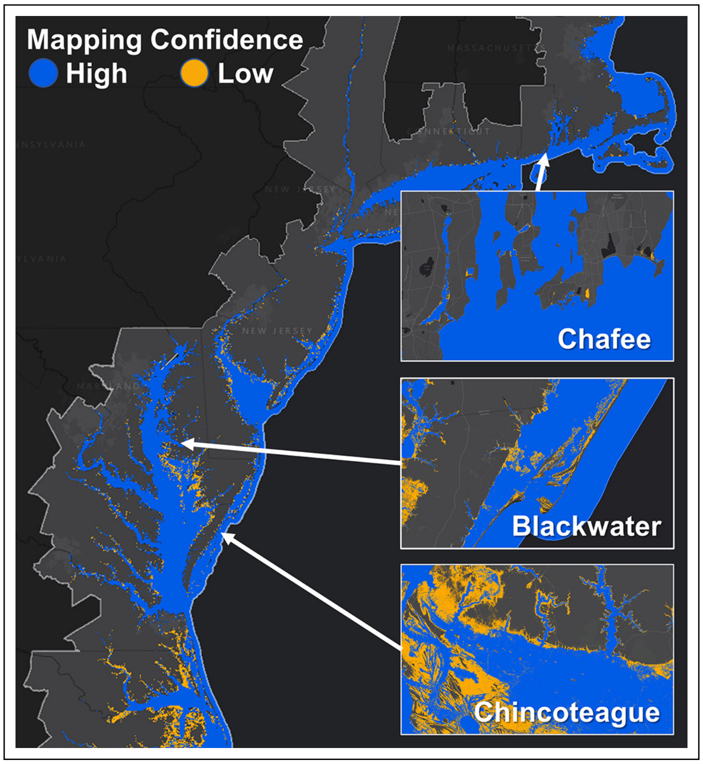


Figure 3. Coastal areas likely to be flooded (blue = high confidence, orange = low confidence) on the Mid-Atlantic and New England coast of the US with a scenario of 0.3 m of sea-level rise (SLR), anticipated before the end of the century, in the National Oceanic and Atmospheric Administration's Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html). (Inset maps) Three National Wildlife Refuges facing ecosystem transformations from SLR.

Blackwater NWR

At the 11,000-ha Blackwater NWR in tidal Maryland, managers chose to *direct* SLR effects by facilitating upslope marsh migration. Nearly 7,000 acres of wetlands in the refuge have been lost since its establishment in 1933, exacerbated by land subsidence, post-glacial rebound, saltwater intrusion, severely modified hydrology, and excessive herbivory from native Canada geese (*Branta canadensis*) and introduced nutria (*Myocastor coypus*) and mute swans (*Cygnus olor*) (FWS 2006). However, the refuge gained new marsh along upland edges, mostly low-lying agricultural lands, presumably through upslope migration. Working with partners, the Blackwater NWR has acquired almost 280 ha of private lands to facilitate additional marsh migration. For example, on the neighboring Farm Creek Marsh, the partnership has launched a \$475,000 demonstration project to facilitate upslope tidal marsh migration by extending the head of a nearby tidal creek 400 m with a low-ground-pressure excavator, which is expected to introduce tidal exchange and support marsh vegetation establishment (see Lerner *et al.*

Table 1. Ecological, societal, and financial factors contributing to the decisions for three National Wildlife Refuges (NWRs) to select among *resist*, *accept*, or *direct* (RAD) strategies in facing sea-level rise

	John H Chafee NWR (*resist*)	**Chincoteague NWR (*accept*)**	**Blackwater NWR (*direct*)**
Ecological feasibility	*Spartina patens* marsh, although exposed to tidal action, was not directly exposed to ocean wave action; upslope marsh migration could not occur because surrounding topography was too steep; test plots already demonstrated existing plants could grow through silt deposition of <15 cm	Long-shore current and island migration were occurring in response to sea-level rise (SLR); hard armoring of northern tip of Assateague Island had proven futile as a means for stopping island migration; unconstrained geomorphological processes will allow natural island movement, ultimately buffering the effects of SLR and future storms as the island moves westward	Upslope migration was occurring unassisted due to extremely low topography; pilot study is underway to test efficacy
Societal feasibility	Marsh restoration was desirable both for wildlife viewing and because marsh loss was increasing shoreline and bank erosion in the Narrow River	Because *acceptance* was highly contentious as Assateague Island protects the Town of Chincoteague from direct ocean surf, the final plan included both federal agencies and the Town of Chincoteague as primary partners; even as dune overwash is being *accepted*, the refuge is constructing artificial oyster reefs (and other actions) to reduce bayside erosion from wave action	Salt marsh loss is important to "watermen" communities in tidal Maryland; southern Dorchester County is rural and poor; buying marginal land is a financial windfall for the community; conversion of salt marsh to open water (ie *accept*) is not considered good by anyone; to protect existing infrastructure, the refuge is using thin-layer deposition to restore marsh in situ
Financial feasibility	Facilitating upslope marsh migration was infeasible because surrounding topography was upland with considerable land development; development of an amphibious excavator and detailed elevational modeling to guide the bulldozer blade within a few centimeters help ensure restoration success	Six decades of primary dune restoration (bulldozing, fencing, planting) have demonstrated its long-term infeasibility; major road, facility, and impoundment infrastructure repairs occurred seven times since 2003 at a cost of ~$3.5 million; two refuge impoundments will fill in and a third will allow overwash; even as existing National Park Service facilities are lost, new facilities are being constructed farther north on the bayside	Facilitating marsh migration is ~ten times cheaper than trying to restore marsh in situ; money has already been invested in eradicating introduced nutria (*Myocastor coypus*) and controlling resident Canada geese (*Branta canadensis*); refuge has already acquired 280 ha of adjacent private lands to allow marsh migration

2013). At the local scale, this action *directs* transformation toward a future desired vegetation community, one of several possible end-states resulting from rising seas. Elsewhere, refuge managers have chosen to *accept* conversion of salt marsh to open water but *resist* salt marsh loss near infrastructure through thin-layer sediment deposition (Figure 4). This portfolio approach addresses the heterogeneity of SLR impacts across the refuge, and incorporates the differential feasibility of alternative responses across the refuge landscape.

Divergent responses to ecosystem transformation

These three NWRs have responded differently to the effects of SLR, partly because of how this global and directional stressor is uniquely manifested in the three geographies, but also because of the surrounding socioeconomic context in which each refuge lies: rural versus urban, barrier island versus coastal salt marsh, as well as different authorities and partnerships. Ecosystem transformation can manifest differently across various spatial and temporal scales or in orders of magnitude (Thompson *et al.* 2021). The decision to embrace one RAD option does not preclude implementation of other options; explicit, intentional implementation of RAD should help managers identify a full array of options, the trade-offs among them, and their sustainability at multiple spatial and temporal extents.

Catalyzing a transition to RAD management for ecosystem transformation

Contemporary conservation and restoration goals increasingly acknowledge that ecosystems evolve through time; however, on-the-ground management approaches continue to implement measures and practices to *resist* change, in order to maintain existing or historical ecosystem structure, composition, and function (ie managing within a familiar, historical range of variability). Under increasing rates and accumulating magnitudes of directional environmental change, particularly climate change, ecosystem transformations will become more difficult to *resist*. Increases in the range of ecosystem variability and uncertainty will be accompanied by decreases in controllability (Thompson *et al.* 2021). Consequently, the cumulative costs of *resistance* may outpace those of *directing* change, despite potentially higher costs in the initial stages of the latter. Furthermore, unwavering adherence to *resistance* poses risks of interruption or diminution of ecosystem services, particularly if ecosystems are susceptible to threshold transformations or contrasting stable states (Millar and Stephenson 2015). In such cases, early intervention to *direct* changes toward a desired future state consistent with the climate trajectory may be most suitable (Hobbs *et al.* 2011).

Approaches that seek to minimize risk of unintended consequences from these novel actions will be essential (Beier and Brost 2010). Issues of scale also complicate this process, as larger spatial extents are naturally more difficult to control. A number of structured approaches and tools in the broader fields of "adaptive management" and "decision science" may facilitate defining and navigating the RAD decision space (WebTable 1). In this rapidly changing new terrain, this toolkit still needs to be tested, refined, and augmented for managers to benefit from iterative application of RAD approaches. To foster the transition to RAD, we propose a suite of guiding principles for informing decisions on how to implement RAD approaches in management of changing ecosystems.

D Curson/Audubon Society

D Harp

Figure 4. (a) Passive revegetation following (b) thin-layer placement at Blackwater National Wildlife Refuge.

Avoid paralysis

Environmental change and ecosystem transformation are inevitably accompanied by uncertainty and variability (Ingeman *et al*. 2019), which can become excuses for inaction. Although impetuous decisions are rarely constructive, delayed action can increase the risk of irreversible change in ecosystem structure, function, and composition, and can result in lost opportunities for *resist* or *direct* strategies and lost time in preparing to adapt to ecosystem changes under an *accept* strategy. Consequently, paralysis can equate to higher cumulative economic costs, greater losses of ecosystem services, and incalculable consequences of irreplaceable natural systems as they transform. Explicitly acknowledging that an ecosystem is at risk of or undergoing transformation and proceeding intentionally with a deliberative RAD approach can help managers make informed decisions and be better prepared for surprises.

Conduct experiments and use pilot testing

To reduce uncertainties about ecological trajectories, experimentation in controlled settings, ideally with replication and controls, can offer greater value for informing proactive course corrections without having to wait for monitoring to resolve the current trajectory (eg experimental restoration of flow; Saunders 2020). Adaptive-management approaches can be implemented within controlled conditions or small management areas to test potential for success before operationalizing fully (Allen and Gunderson 2011). Pilot studies and experiments are ways to reduce uncertainty and paralysis, providing data to improve performance, reveal problems, and advance managers' information base prior to implementation.

Consider multiple strategies

Ecosystem transformation occurs across multiple spatial and temporal scales. Combinations of RAD strategies may be needed, depending on ecosystem status, management goals, and availability of resources, particularly space. Larger areas can provide an opportunity to employ multiple strategies concomitantly without committing to just one decision for the entire landscape or region. A key aspect of considering these options is time: at what point does one cease *resistance*, or commence *directing* change? A portfolio of approaches implemented across space can improve managers' ability to assess the ecological, societal, and financial feasibility of competing options.

Identify tipping points

There may be environmental tipping points (eg exceeding critical thermal maximum, loss of enough topsoil to change germination potential, alterations in wildfire regimes that favor new species over native ones), biological tipping points (eg loss of a seed bank, establishment of an invasive grass that sets off a wildfire-based positive-feedback system), or financial tipping points (eg reduction in fish abundance such that recreational or commercial fisheries are no longer viable) whereby the costs of *resistance* are no longer affordable or tolerated by society. Beyond these tipping points, *resistance* is a futile and ineffective management practice. Although predicting when a tipping point will be reached will often be difficult, there are a number of quantitative and qualitative techniques that can help (Martone *et al.* 2017).

Maintain management flexibility

Present-day decisions have future implications, and effective management of ecosystem transformations may seek to avoid decisions that inadvertently preclude future options as circumstances change (especially rates of directional change). Regulatory interventions that establish entitlements may be approached with caution to reduce risk of committing to ecosystem services that become unsustainable under transformation (eg perpetual harvest rights). Similarly, bet-hedging approaches can include restricting novel management actions to a sub-portion of a system, implementing "sunsets" that obligate management reassessment and course corrections, and maintaining options for alternative actions, should things go wrong (Aplet and McKinley 2017).

A RADical new frontier

We currently face a lack of precedents and high uncertainty regarding this new frontier. As more ecosystems pass beyond the point of feasible *resistance*, managers will actively need to decide whether to *accept* changes or *direct* changes toward desired outcomes. One of the most pragmatic aspects of the RAD framework is that it encompasses the entire decision space for responding to directional changes and so forces explicit action (ie there is no other choice beyond these three options). Managing ecosystem transformation is surely a daunting task, but it is already a reality for many natural resource managers who are "learning while doing" (Doremus 2007). RAD will have expanding relevance in this era of global change and taking calculated risks may be the best way to proceed.

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