Restoration Scaling in the Face of Non-Stationarity and Uncertainty

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Introduction

Ecologists have long recognized that interactions among natural and human stressors are key drivers of ecosystem change. The traditional view has been that despite these drivers of change, most ecosystems are in dynamic equilibrium and fluctuate within an unchanging "envelope of variability" (Milly et al. 2008). Restoration ecologists and planners have traditionally incorporated an implicit assumption of stationarity when planning and designing habitat restoration. However, there is growing recognition that anthropogenic climate change and other global stressors are altering the variability of indicators of ecosystem structures and functions and fundamentally altering ecosystem dynamics and the assumption of stationarity. In a number of cases, the mean level of population fluctuations is changing with time, and some recent studies suggest that as variance increases, the potential for reaching a tipping point that results in significant regime shifts also increases. These observations point to the need to incorporate the variance in physical and biological conditions in ecosystem assessments and restoration planning. Yet there remains little guidance on how to apply this understanding to restoration planning and management, especially when using restoration planning and scaling tools. The objective of this poster to present concepts on how to adapt Habitat Equivalency Analysis (HEA), Resource Equivalency Analysis (REA), and Value Equivalency Analysis (VEA), or how to develop new methods for restoration scaling; that recognize and address the challenges of quantifying ecological value in a changing environment. Because we are presenting major concepts rather than detailed examples of method changes, we use the terms HEA, REA, and VEA interchangeably for brevity while recognizing the differences between the objectives and applications of these analyses.

Under many regulatory programs (e.g., Clean Water Section 404 or Endangered Species Act Section 7), compensatory restoration was based on replacement of affected areas on an acre to acre basis with some additional factor (e.g., 3x) to account for uncertainty. Tools such as HEA, which was developed to support Natural Resource Damage Assessment (NRDA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Oil Pollution Act (OPA), recognize not all impacted and restored areas are functionally equivalent and instead focus on restoring lost ecosystem services. HEA was developed as a scaling method to evaluate ecosystem service losses due to injury or disturbance and restoration gains over time and space, and is applied as a surrogate for habitat valuation to define compensatory restoration. In recent years HEA has been applied to other perturbations of aquatic and terrestrial systems such as evaluation of impacts from major forest fires (Kimball 2009) and mitigation of new transmission lines (SWCA 2012). HEA has typically been applied as a deterministic model that implicitly assumed stationarity of environmental conditions for establishing baseline conditions and scaling ecosystem losses with ecosystem recovery and restoration gains.

What is Non-Stationarity?

Stationarity is a statistical concept that assumes statistical properties are constant over time. When applied to natural systems, stationarity assumes that natural systems fluctuate in a predictable manner, the parameters of which can be estimated from the instrumental record. Practically, assuming stationarity means that, with a dataset of sufficient size, key inputs defining environmental conditions and biological responses can be identified with an acceptable statistical accuracy and precision. However, the efficacy of stationarity in modeling natural systems has been challenged. Milly et al. (2008, p. 273) famously declared that, because of climate change, **"stationarity is dead and should no longer serve as a central, default assumption in water resource risk assessment and planning."**

Non-stationarity refers to the changing distribution of statistical data over time. In the context of natural systems, non-stationarity characterizes meteorological extremes and their distribution over time and space. These extremes, which are indications of climate change, have direct, indirect, and long-term effects on species and communities. Non-stationarity results in changes to daily and seasonal meteorological and climate parameters, related oceanographic conditions, and to disturbances that alter environmental baselines. Other environmental influences, which may be indirectly related or unrelated to climate change, can result in non-stationarity, such as introduction of invasive species, disease, severe fires, or human development. Scaling compensation using HEA or other existing methods is challenging under circumstances of non-stationarity.

Species and communities will experience a variety of non-stationarity stressors, as follows:

- Extreme high temperature
- Extended periods of extreme temperatures and low precipitation causing extended drought
- Increased severe intensity forest and grassland fires
- Extreme precipitation events (amount, intensity, frequency) with associated floods
- More frequent and more intense hurricanes and tropical storms
- Increased intensity of wave disturbances and storm surges
- Changes in snow cover and its implications on the hydrological cycle
- Reduction of sea ice in the Arctic Ocean
- Community interactions due to species distribution shifts or range extensions

Agencies' Response to Climate Change and Non-Stationarity

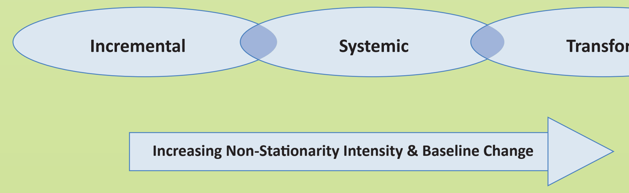
With respect to concerns over the effects of climate change and sensitive ecosystems, restoration planning and execution proceeds within a broad context of federal, tribal, state, regional, local and interagency planning, monitoring, adaptation and implementation policies, programs, initiatives, guidance and plans. For example, the National Fish, Wildlife, and Plants Climate Adaptation Strategy Partnership (2012) identifies goals and actions that are applicable nationwide. Review of this strategy and other materials (see "Selected Policies, Programs, Initiatives, Guidance and Plans" under *References*) yielded the following common strategies for responding to climate change and non-stationarity in the context of restoration.

- Conduct an inventory of affected resources.
- Identify regional and local stressors.
- Identify the most vulnerable species, habitats, communities and ecosystem services.
- Identify pertinent reference conditions.
- Develop or use existing decision support tools (geospatial, ecological modeling).
- Be science-based and collaborative (interagency, intergovernmental, Tribes, public).
- Identify priorities considering cost, effectiveness and resilience.
- Develop strategies, tactics and plans.
- Monitor the impacts of restoration on affected resources.
- Evaluate effectiveness of restoration.

Intensity and Timeframes of Changing Conditions

A critical early step in accounting for non-stationarity is to evaluate how conditions may change over time. Although there are numerous methods available, Vermeulen et al. (2013) suggested grouping changes in stressors, associated changes and responses in the context of incremental, systemic, or transformative categories (Figure 1). Anticipated changes along this gradient will reflect increasing non-stationarity intensity and increasing changes in baseline conditions.

FIGURE 1: Putting non-stationarity in context of level of intensity.



The applicable timeframes for the incremental, systemic, and transformative categories could range from very short to longer term depending on the species, communities, and the types and intensity of non-stationarity stressors. Figure 2 presents example timeframes and a selection of concepts for consideration of how species and communities might react.

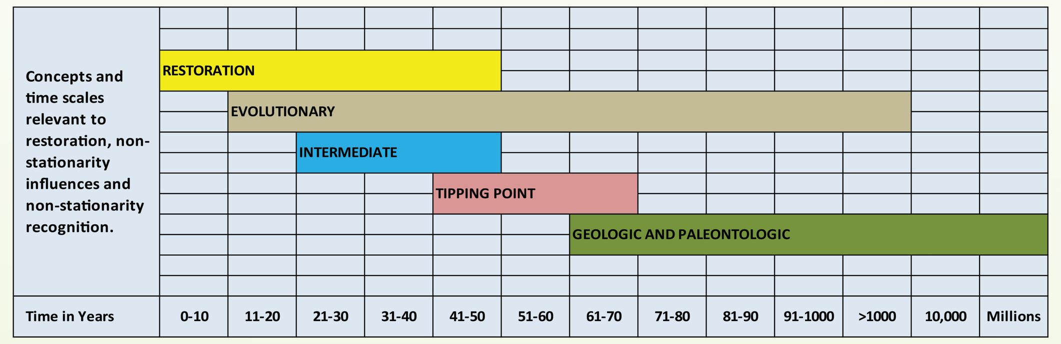


FIGURE 2. Concepts and timescales relevant to restoration, non-stationarity influences and non-stationarity recognition. Categories and timescales are not all inclusive and are meant for discussion. Length of timescale bars and their overlap would vary depending on environment/niche being restored and on rapidity of non-stationarity/meterological/climate influences, including local and pertinent climate velocity (terrestrial, riverine, lacustrine, marine). (e.g., Isaak and Rieman (2013), Dobrowski et al. (2013))

Descriptions

- Restoration: "standard restoration timescales of several to 25 to 50 years plus; varying opportunity to restore and maintain "current species and community distributions.
- Intermediate: non-stationary and stressor impacts evident; regime shifts, nove communities.
- Evolutionary: timeframe varies with sepcies, community, environment, stressors, and the rapidity of "generational" overturn
- Tipping Points: non-stationarity and stressor impacts cause substantial shifts in communities.
- Geological and paleontological: informed by geologic record; no analog communities; deglacial through early holocene migrations; long-term (tens of thousands to hundreds of millions of years) environmental changes and ecological response.

Implications of Climate Change for Restoration Planning

Baseline data should reflect conditions that would have been expected had the disturbance not occurred, taking into account both natural and anthropogenic processes. Baseline data should include the normal range of physical, chemical, or biological. Causes of extreme or unusual values in baseline data should be identified and described (Department of Interior NRDA regulations (43 CFR 11.72(b)(1-3)).

Figure 3 (Rohr et al. 2013) provides an overview regarding how climate change may impact baseline conditions and restoration requirements when using habitat equivalency analysis (HEA) to determine primary and compensatory restoration requirements.
Hanson et al. (2013) presents some theoretical differences in baseline conditions when using HEA to assess losses from severe forest fires. For HEA to be valid in such applications, risks from fire, insect infestation, and disease must be incorporated in the baseline condition of high risk, overstocked forests. However, although fire and disease may be incorporated in the baseline conditions (absent the fire of interest being evaluated), it is uncertain when, or how severely, the baseline conditions would be affected by such threats.

Figure 4 Panel A depicts an assumed stable baseline and the theoretical baseline level of services following a severe forest fire. Under this scenario, Area 1 in Panel A depicts the service acre losses.

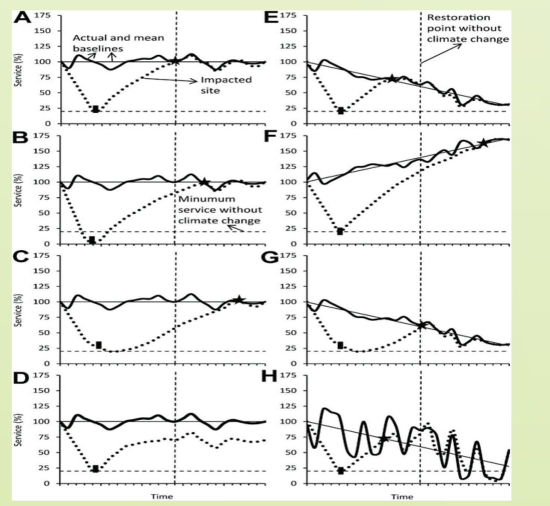


FIGURE 3. Illustration of how climate change can drive significant differences in baseline conditions, as well as primary and compensatory restoration using HEA (from Rohr et al. 2013)

Baseline and primary restoration cenarios without (A) and with (B-H) global climate change. Climate change can delay recovery/restoration (star) by additively or synergistically interacting with hazardous substances such that the initial rate of decine of services is greater (B) or the rate of recovery is less (C) than in the absence of climate change. Climate change might also prevent services from ever returning pre-injury baseline conditions (D). Baseline services could also decrease (E) or increase (F) with climate change, which can accelerate or delay recovery/restoration, respectively. Additionally, there can be combinations of the aforementioned effects that can affect change-induced decreases in baseline services and rates of recovery/restoration (G) or climate change-induced decreases in baseline services and increases in baseline variability that can make it more challenging to assess injury and restoration (H). For simplicity, stochastic variability in the contaminated site is not shown until it returns to the baseline condition.

Implications of Expected Stressors with Unknown Timing

Panels B and C depict the same environmental disturbance but demonstrates the effects of different baseline conditions. Panel B adds a depiction of a declining pre-fire baseline due to competition-stressed vegetation followed by a stand-changing event at time Tc. The stand-changing event could happen at any time along the X axis unless forest restoration is undertaken (shown at time Tr) and/or maintained at sufficient level to reduce stand-changing risk from fire, insect infestation, and disease. Under this scenario, the loss from the fire of interest would be equal to discounted Area 1 of Panel B less the discounted Area 2 because ecosystem services after the fire would exceed the ecosystem services under baseline conditions.

Panel C acknowledges that, at this point, we have not predicted when the "all else equal" baseline event will occur. Comparing Panels A, B, and C demonstrates that simply agreeing that a fire is likely to occur at some time in the future is insufficient to determining net loss attributable the fire of interest from a more realistic depiction of the future forest condition.

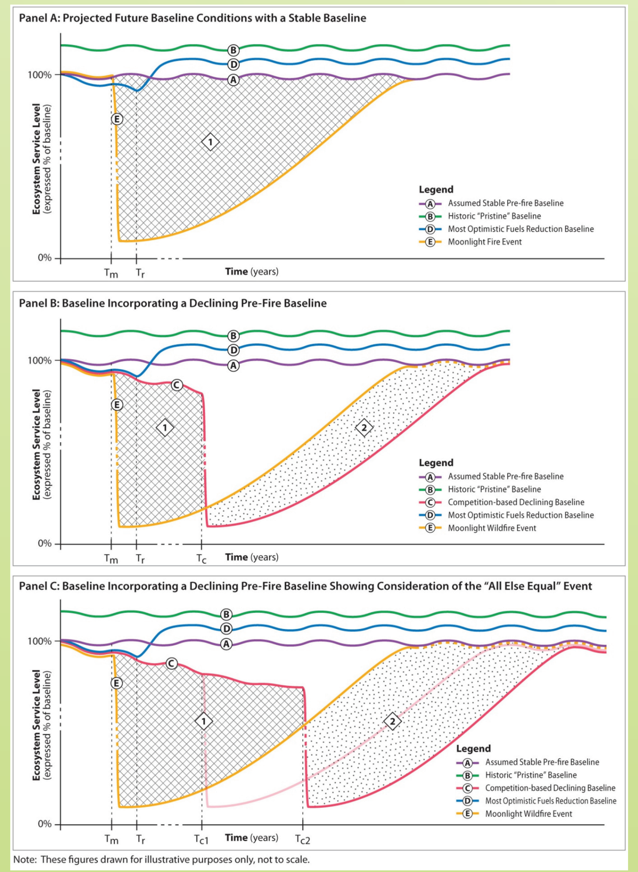


FIGURE 4. Implications of expected, non-stationarity disturbances on baseline conditions and ecosystem service loss of unknown timing. (from Hanson et al. 2013)

Align Discounting with Resiliency Building

With HEA, restoration scaling incorporates a discount rate to bring past ecosystem losses and future gains to a net present value in order to scale the size of the restoration based on the assumed preference towards having a restoration project restore function in the present year rather than sometime in the future. Dunford et al. (2004) provides an analysis of the theory and implications of various discount rates in HEA. The U.S. Environmental Protection Agency (EPA) (2010), in its *Guidelines for Preparing Economic Analyses* addresses ethical issues for discounting benefits to future generations. EPA states if the policy has a long time horizon (more than 50 years or so) where net benefits vary substantially over time—most benefits accrue to one generation and most costs to another—then the analysis should use the consumption rate of interest as well as approaches such as calculating the expected present value of net benefits using an estimated time-declining schedule of discount factors.

Use of a uniform discount rate, as typically used for restoration planning, is inconsistent with EPA's intergenerational approach for addressing the impacts of climate change. Use of a uniform discount rate will favor restoration alternatives with short-term goals consistent with those developed under the implicit assumption of stationarity because the anticipated impacts of non-stationarity (whether a measure of ecosystem loss or restoration gain) are heavily discounted. This may be in direct conflict with adapting and implementing restoration alternatives and goals that recognize non-stationarity and are designed to improve ecological resiliency.

Choose Between What Was, What Would Have Been, and What Could Be

Restoration goals help determine restoration targets and guide the monitoring metrics that identify failure or success. In NRDA, the restoration goals may include achieving pre-disturbance baseline conditions for species, habitats, and services as well as providing compensatory services to account for those lost in the time prior to full restoration. The need to demonstrate equivalency of the restored resources relative to baseline favors goals that value in-kind and proximate (local or onsite) restoration over out-of-kind or remote restoration. This may result in restoration goals focused on returning resources to pre-disturbance conditions (White and Walker 1997, Swetnam et al. 1999, Egan & Howell 2001), and does not typically result in restoration that account for non-stationarity or that adds ecological resiliency (Harris et al. 2006). Establishing restoration goals that account for non-stationarity is the critical first step in planning restoration that accounts for future uncertainty and changing conditions. This requires some important policy and procedural decisions regarding the following approaches:

- Conducting based on affected species (regardless of location) versus focusing on enhancing site productivity.
- Selecting the approach applied to scale restoration (e.g., HEA, REA, or VEA).
- Determining how habitat connectivity and genetic diversity increase ecosystem flows.

With a longer timescale, accounting for non-stationarity means that restoration goals will need to account for current conditions and future scenarios as follows.

1. Take into account non-stationarity (how conditions are projected to change)
2. Balance local natural capital versus long-term species management and ecosystem resilience
3. Accomodate metrics to demonstrate equivalency; restoration may or may not be in-kind, or service-to-service
4. Include actions that serve long- term species resilience such as off-site or "out-of-kind" actions or restoration if future local scenarios are not projected to be conducive to restoration and species viability.

TABLE 1. RESTORATION GOALS IN RELATIONSHIP TO SHORT- TO LONG-TERM TIME FRAMES. Illustration of how climate change can drive significant differences in baseline conditions, as well as primary and compensatory restoration using HEA.

Goal Type	Short Term (status quo; account for historic variability in last 100 years)	Long Term (account for non-stationarity)
Species Specific	• On-site or local (within close proximity to injury/loss). • Focused on conserving and restoring currently suitable habitat, or other management measures to enhance existing, local populations	• Expanded focus on species range and connectivity between existing and marginal/fringe habitats with a potential for increased suitability in future (e.g., higher elevations, increased latitudes). • Measures to protect genetic diversity and thus ability to adapt.
Habitat Specific	• Habitat restoration designed to be succesful given historic *and recent* conditions • Locally sourced plant materials.	• Forecast how abiotic conditions may change (growing season, water budget, seasonal high and low temperatures, water flood/storm surge frequency and extremes). • Create or utilize gradients that accomodate changing conditions (e.g., sea level) and connectivity with typically adjacent habitats. • Spatially diverse plant sources to increase genetic diversity.
Ecosystem (aggregation of habitat elements and ecosystem processes)	• Accomodate ecosystem processes. • Create habitat mosaics and connectivity informed by current *and recent* conditions.	• Accomodate ecosystem processes and natural infrastructure that modulates extremes *and improves connectivity over time* sediment source, flood plains, coastal wetlands, mangroves, sea grass beds, oyster reefs, coral reefs. • Create habitat mosaics and connectivity informed by current conditions and future trajectories.
	(short-term) Species-Oriented	TIME (long-term) Ecosystem/Habitat-Oriented

References: Harris et al. 2006, Schloss et al. 2011, Rohr et al. 2013.

Accomodate Uncertainty in Restoration Scaling Tool Structure

As presently used, HEA is a deterministic model with few or no stochastic elements. Temporal impacts are assessed using a time-series of steady state events in order to equate the net present value of service losses with the net present value from compensatory restoration. Variability of model input parameters may be calculated using a weighted probability of an individual variable in order to report a deterministic model result. Concerns of non-stationarity in HEA analyses are often ignored because of the uncertainty with selected model inputs or the interactions between model inputs.

An alternative approach to incorporate non-stationarity is to develop a stochastic model of the expected outcomes using Bayesian networks or Monte Carlo simulation. The peak in the distribution of Monte Carlo model outcomes represents the best estimate of expected value. This approach more accurately summarizes the level of certainty in the analysis and help define which model inputs and approaches have the greatest impact on the results, thus guiding future studies based on the value of information. If acceptable estimates of selected input parameters cannot be provided for a stochastic model, scenario-based approaches should be considered to address those parameters.

Stochastic models of expected value, supplemented with scenario modeling, can be used to address non-stationarity more appropriately than current deterministic methodologies.

Presented at: 5th National Conference on Ecosystem Restoration (NCER), July 29-August 2, 2013, Schaumburg, IL

Incorporate Geospatial Relationships to Address Connectivity and Resiliency

One of the central problems in ecology and conservation biology is the drastic impact of anthropogenic action on landscapes, which result in habitat loss and fragmentation. Habitat connectivity is an indicator of the extent of habitat fragmentation. The heterogeneity and connectivity of habitat conditions are important measures of habitat value for both scaling of habitat losses and the selection and design for habitat restoration. The National Fish, Wildlife, and Plants Climate Adaptation Strategy calls for conserving and connecting critical ecosystem habitats as an adaptation approach to dealing with climate change.

Habitat connectivity is also defined by species. Small, relatively non-vagile species may require fully connected habitats while wide-ranging species can use and disperse over more fragmented landscapes. For example, migrating birds use physically disconnected habitats as connected, non-fragmented habitats if these disconnected habitats contribute to successful migration.

Figure 5 provides an example of the importance incorporating meaningful indicators of geospatial relationships for defining habitat value and connectivity in future uses of HEA and/or similar restoration scaling methods. HEA and most other resource and land management programs model and sum changes by categories but do not track critical relationships between habitat categories, life history requirements, and other critical ecosystem functions. Following the "what gets measured gets done" philosophy, scaling tools such as HEA need to incorporate and value applicable metrics of ecological connectivity to in order to align restoration designs with climate adaptation goals.

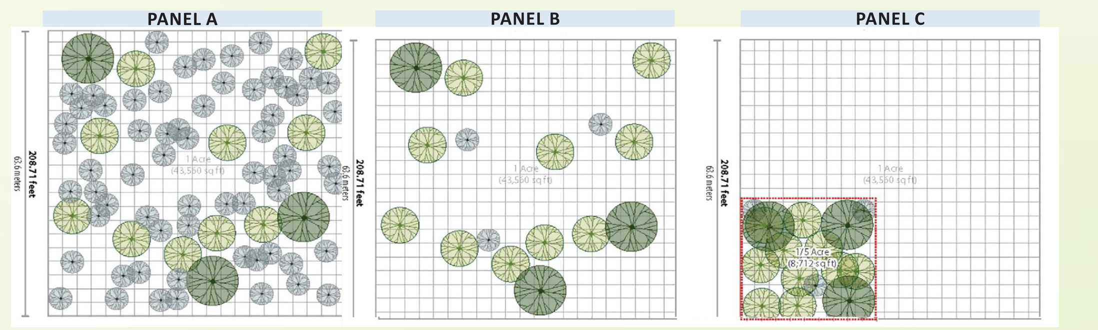


FIGURE 5. Visual example of importance for maintaining geospatial relationships in scaling methodologies. Panels B and C bothrepresent an 80 percent mortality-weighted impact following a severe forest fire compared to pre-fire conditions (Panel A). Although the impact scenarios depicted in Panels B an d C are mathematically equivalent using HEA, in reality they would have significantly different ecological value and recovery curves. (Adapted from Hanson et al. 2013).

Provide Incentives for Desired Outcomes and Objectives

When restoration is required to compensate for ecological resource losses or damages, it is a simple economic reality that liable parties will seek the most cost effective-restoration projects that will satisfy restoration requirements. If regulators want to ensure that restoration accounts for non-stationarity, then they must make policy decisions that incorporate these other measures that incentivize specific actions or restoration project attributes. Moreover, the metrics or other incentives need to be commensurate with the relative cost of adding those attributes. Table 2 summarizes the conceptual metrics that could be used to provide incentives for specific actions.

TABLE 2. Potential approaches for incentivising restoration design to accommodate non-stationarity and building ecosystem resilience.

Habitat type	Nonstationarity Value	Possible Metric or Credit
Seagrass	Provides wave attenuation, reduce coastal erosion and storm surge.	Credit: include restored area plus a portion of the habitat values protected by seagrass.
Riverean	Off-channel resting and nursary area in high velocity rivers in urban environments with minimal natural habitat.	Metric: Incentivize restoration for highly developed areas based on ecological value.
Upland	Habitat connectivity corridor if upland connects restored habitat to existing habitat.	Credit: include restored area plus a multiplier applied to the value of the connected habitat.
Tidal marsh	Source genetically diverse plant materials from temperature, moisture, or salinity extremes.	Metric: greater genetic diversity increases the resilience of planned communities.
Riparian	Widen and add gradual grade to accommodate future water levels. Wider riparian area can also provide additional flood water storage.	Metric: compound interest rate to value spatial flexibility and multiplier to account for flood storage capacity.

Climate-Proof Restoration Plans

Climate change affects natural resources and the abundance and distribution of species in a number of ways (Table 3). These effects have important implications for restoration projects, including determination of baseline and recovery trajectories and approaches to adaptive management.

TABLE 3. Current and projected impacts of Climate Change in the United States.

Category	Current and Projected Impacts	Examples of Impacts to Natural Resources
Temperature	• Average air temperature has risen more than 2 degrees Fahrenheit over the past 50 years and is projected to rise more in the future. • Ocean temperatures are also rising.	Drought; increased frequency of large wildfires; insect infestations; changes to habitat and species loss; melting of glaciers. Stronger storms with higher wind speeds and more rainfall; coral bleaching. Species distribution shifts/range extensions.
Precipitation	• Precipitation has increased an average of about 5 percent over the past 50 years. Northern areas are predicted to become wetter and southern areas, particularly in the West, drier. • Amount of rain falling in heaviest downpours has increased about 20 percent on average in the past century, and this trend is likely to continue with the largest increases in the wettest places. • In most regions, the fraction of precipitation falling as rain has increased.	Increased flooding in some areas; more severe drought in some areas. Loss of snow cover. Changes in the hydrological cycle, impacting peak, average, and minimum stream flows. Altered habitat suitability for fish and wildlife (insufficient flows for spawning, loss of side channel nursery habitat).
Extreme Weather Events and Storms	• Many types of extreme weather events (e.g., heatwaves, droughts) have become more frequent and intense. • Destructive energy of Atlantic hurricanes has increased, and intensity of these storms and associated wind, precipitation, and storm surges are expected to increase. • Cold season storm tracks are sshifting northward, and the strongest storms are likely to become stronger and more frequent.	Flooding, erosion, and inundation of coastal ecosystems. Altered habitat.
Sea Levels	• Sea level is increasing along most of the U.S. coast, with the magnitude varying by region depending on factors such as local land subsidence.	Inundation of some coastal areas; erosion; changes to habitats and possible species loss due to saltwater intrusion, etc.
Ocean Acidification	• Seawater is becoming less alkaline (pH is decreasing) as the ocean absorbs more and more carbon dioxide from the atmosphere.	Reduces shell fromation and skeletal development of corals, mollusks, and some plankton species important to ocean food chains.

Modified from: GAO. 2013. Climate Change. Various Adaptation Efforts Are Under Way at KeyNatural Resource Management Agiencies. Report to Congressional Requesters. GAO-13-253.

A key approach for managing trajectories of change is to build ecological resilience. Climate-proofing describes measures take to increase the resilience of restoration projects in the face of climate change. Chapin et al. (2009) define resilience as the capacity of a system "to absorb a spectrum of shocks or perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks as a result of recovery or reorganization in a new context." Although environmental liabilities are defined by the need to restore conditions to the pre-perturbation baseline, there is an implicit assumption that the pre-disturbance baseline was stationary and sustainable. Chapin et al. identify three broadly overlapping sustainability approaches:

- Reducing vulnerability to expected changes.
- Fostering resilience to sustain desirable conditions in the face of perturbations and uncertainty.
- Transforming from undesirable trajectories when opportunities emerge.

Climate-proofing and adaptation can contribute to all three approaches. However, transforming from an undesirable trajectory and including sustainability in the restoration goals may run counter to existing regulations, policies, and guidance. Policy studies identifying barriers and opportunities to integrate restoration planning with building resiliency are recommended.

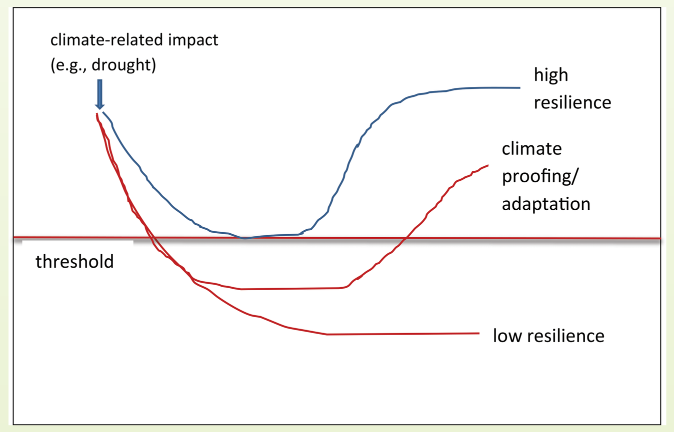


FIGURE 6. Climate proofing to achieve sustainable restoration design despite climate related impacts.

Create Restoration Portfolios

The recommendations provided in this paper are meant as a starting point for adapting and developing new methods and guidance to align HEA with adaptation strategies for non-stationarity. Even if these recommendations are fully developed, non-stationarity by definition represents significant risks to restoration plans and it may not be possible to fully address non-stationarity on a site-by-site basis. As a result, creating a portfolio of restoration efforts that satisfy short-term primary and near-term compensatory restoration needs while also including restoration projects that incorporate long-term trajectories may prove a robust strategy to further hedge against risks and develop sustainable restoration.

Summary

Given the increasing evidence of non-stationarity, it is essential that restoration planning develop approaches to address the changing variance in ecosystem conditions. In the case of NRDA, this creates significant need and opportunity for fundamenchanges in existing methods or new methods to accommodate changing baselines, ecosystem trajectories, and uncertainties as restoration progresses. The first challenge is defining how non-stationary baselines may fluctuate and then scaling restoration to potential future scenarios under changing and uncertain conditions. Another challenge is to consider the legal and policy issues around designing restoration based on potential future, rather than current actual, conditions as well as climate adaptation and resilience goals. Rather than recovery to baseline, the goal may becomes building resilience and the capacity of the ecosystem to sustain fundamental structures and functions in the face of increasing variability. In this context, monitoring and adaptive management of restoration will take on increasing importance, and a key challenge will be how to adjust regulations to account for non-stationarity.

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Selected Policies, Programs, Initiatives, Guidance and Plans
White House CEQ Interagency Climate Change Adaptation Task Force
NOAA Climate Smart Sanctuary Initiative (National Marine Sanctuaries)
National Park Service Climate Change Action Plan
USFWS Strategic Direction for Climate Change including 'Refuge Vulnerability Assessment and Alternatives Technical Guide'
USDA Forest Service Strategic Framework for Responding to Climate Change
Landscape Conservation Cooperatives (USFWS, NPS, USFS, BLM, NOAA)
Other federal agencies: U.S. Army Corps of Engineers, Federal Highway Administration, US Geological Survey, National Resource Conservation Service, Environmental Protection Agency

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