Adaptive Management of Climate Change Impacts on Ecosystems: Some Personal Perspectives

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Adaptation to climate change will require radically different paradigms in ecosystem management to:

- cope with climatic non-stationarity in resource and ecosystem management
- engineer the products of succession to prevent regional synchroneities and inhibit undesirable species invasions following large-scale disturbances
- anticipate and direct migrations in ways that hedge our bets, mitigate adverse effects, and enhance ecological goods and services.

Below, I elaborate on these objectives, which will be the focus of my comments in the panel.

I. Climatic change compromises a central tenet in water and ecosystem management that natural systems fluctuate within an unchanging and well-defined envelope of variability. These assumptions are embodied to varying degrees in the concepts of Hydrologic Stationarity (HS) and Historic Range of Variation (HRV). Adaptation to climate change will require retooling these traditional methods and developing alternative ones that are better suited for managing resources and ecosystems under a nonstationary climate.

Water professionals around the world have always had a challenging job: How do you balance water supply and demand and minimize risks to life and property when you can not foresee the future? Until now, looking back at historical observations has been a serviceable way to estimate future conditions but climate change increases the chances for droughts or floods unmatched in the past in timing, frequency, or intensity. A planner must now ask whether his/her system will have more water, less water, at the right time or wrong time. Decisions on adaptation to climate change can depend critically on the answers to these questions. Do increased drought risks justify new water-conservation policies and water-supply reservoirs? Do increased flood risks require new flood-control reservoirs and/or flood-plain regulation? The answers to these questions depend largely on what the future holds.

Systems for management of water throughout the developed world have been designed and operated under the paradigm of Hydrologic Stationarity (HS). The stationarity assumption posits that any hydrologic variable (e.g., annual streamflow, annual maximum flood) has a time-invariant probability density function (pdf) whose properties (mean, standard deviation, correlation structure, long-term persistence, etc.) can be estimated from the instrumental record. Stationarity implies that the future will be statistically indistinguishable from the past. Under a stable climate, this statistical concept has simplified the task of managing water systems in an economically efficient and effective manner. Given the magnitude and time lags of climate change associated with the buildup of greenhouse gases, stationarity may indeed be dead (Milly et al. 1998).

A viable successor to stationarity must encompass principles and methods for identifying non-stationary probabilistic models of relevant environmental variables and for using such models to optimize water systems. Non-stationary hydrologic variables can be modeled stochastically to describe the temporal evolution of their means and variances, with estimates of uncertainty. Rapid flow of climate-change information from the scientific realm to water managers will be critical for planning under non-stationarity, because the information base is likely to change rapidly as climate science advances during the coming decades. Essential to the new paradigm is a stable institutional platform for climate predictions and climate-information delivery, namely climate models that don't need to be adjusted for biased or downscaled and include faithful representation of the hydrology, the land cover, and water and land use. Optimal use of available climate information will require extensive training of incumbent and upcoming hydrologists, engineers and managers in nonstationarity, uncertainty, and climate modeling.

The stationary paradigm has not had the same prominence in ecosystem management as in hydrology and water planning. Unlike surface and ground water, terrestrial ecosystems have not been uniformly monitored with broadly applicable metrics and agreed-upon standards over a long period of time and across the country, much less the world. The closest approximation is the recent (since the 1990's) use of Historic Range of Variation in forest management. HRV is estimated as the range of some condition or process that has occurred in the past, in essence some bounded variation in behavior over time. The metrics for these conditions and processes are diverse (e.g., fire interval, stand structure, diversity, patch size, etc.), and are usually reconstructed with poorly-defined uncertainties at a few sites that may or may not be representative of the overall landscape. In some cases, stationarity has been assumed to parameterize climate variability in landscape models and that is no longer defendable.

Finally, there is some discussion about whether history is still relevant in a non-stationary, non-analog world (Millar et al. 2007). It most certainly is. Knowledge about ecological responses to past environmental variability is essential to shed light on the range of potential responses to future conditions. Historical trajectories of pattern and processes in ecosystems and landscapes should continue to be integrated into projections of future climate, land use and invasive species spread. Methods for estimating model parameters can be developed to integrate historical and paleo-hydrological measurements with differing projections of multiple climate models, of varying skill, driven by multiple climate-forcing scenarios. In hydrology, optimal observational strategies based on stationarity favored the relocation of streamgages over time. In a non-stationary world, continuity of observations will be of even greater value. Stationarity may be dead, but history is alive and well.

The above discussion was synthesized from the following publications:

Millar, C.I., N.L. Stephenson, and S.L. Stephens. 2007. Climate Change and Forest Change and Forests of the Future: Managing in the Face of Uncertainty. Ecological Applications 17(8): pp 2145-2151.

Milly, P.C.D., Betancourt, J.L., Falkenmark, M., Hirsch, R.H., Kindzewicz, Z., Lettenmaier, D.P., Stouffer, R.J., 2008, Stationarity is dead: Whither Water Management-Rethinking approaches to planning and design in a chaning climate. *Science* 319, 573-574.

2. *For ecosystem management in the western U.S., the new focus should be on how to forecast, monitor and engineer the products of succession on a regional to subcontinental scale. We can passively adjust to the consequences, or we can try to identify points and scales of intervention where we can proactively determine the outcomes of succession for specific goods and services under a changing and uncertain climate.*

In the last two decades, much of the focus in managing western forests has been to reduce stem densities and lessen the risk of catastrophic fires and other disturbances, the principal focus of the National Fire Plan, the Healthy Forest Initiative and the USDA Joint Fire Sciences Program. In deserts and rangelands the emphasis has been on slowing the spread of non-native grasses (e.g., cheatgrass, red brome and buffelgrass) that increase the risk of large fires in vegetation types that seldom or never burned. Although there have been a few successes, the rate of fires and other ecological disturbances continues on the rise.

Along with the accumulation of fuels- due to historical grazing and fire suppression in southwestern ponderosa pine forests and grass invasions in the deserts- warming and lengthening of the growing season is increasing fire frequency, intensity, extent and large-scale synchroneity and may also be amplifying insect outbreaks and drought-induced tree dieoffs. The warming and longer growing season may also be accelerating succession after these disturbances. The degree of ecological synchrony associated with global warming in large part will determine future resilience to perturbations, risk of population or species extinction, invasibility of ecosystems, and management costs. Wise management of western ecosystems might well involve systematic and proactive efforts to throw Nature out of phase, rather than allow it to further synchronize out-of-control.

Perhaps what we most need in the West is a USDA-DOI Joint Ecosystems Change Program that acknowledges that we should immediately start managing for abrupt ecosystem change following ecological disturbance. Two important assumptions of such a program are that: (1) it is easier, cheaper and more effective to manage/manipulate the earlier than later stages of succession (the fuels treatment program focused on millions of acres of mature forests, which made the task daunting and impossible); (2) regional plans to manage the products of succession can actually be implemented across multiple jurisdiction and at regional scales. Such regional management efforts will require a sustained and well-organized series of post-disturbance treatments to disrupt ecological synchrony (making the managed "natural" systems patchier and thus more resilient to climatic variability and change).

3. *The most effective strategy to manage the ecological impacts of climate change could in fact be how we prevent and assist species migrations across humanized landscapes.*

A controversial proposition in the conservation community is whether or not we should relocate species threatened by climate change. Do we know enough to do it right without unintended consequences? For some of us, assisted migration is a scary thought, akin to playing God with Nature. As humans, however, we do it all the time, both on purpose and by accident. That’s how we ended up with saltcedar along our streamcourses, and red brome and buffelgrass in our deserts. But it’s not just about introductions; it’s also about how we’ve influenced dispersal. For some native species, we block dispersal unintentionally through our fragmentation of landscapes and disruption of pathways. For those species, native or non-native, capable of hitching a ride on an automobile, a train or a plane, we have magnified distances and probabilities of long-distance dispersal in unprecedented ways. If this is truly significant, the first set of wholesale plant migrations associated with global warming could in fact happen south to north along interstate highways. Have we even bothered to look? Are we now prepared to correct our unintentional influences on dispersal in the context of climate change?

For example, in managing succession after large-scale disturbances, will we emphasize "plantings" that ensure that the right mix of genotypes and species are locally available to hedge against the next century of climate change. At a recent meeting on invasive species and altered fire regimes in the American Deserts, much of the discussion focused on post-fire seeding after individual cheatgrass and red brome fires that covered tens to hundreds of thousands of acres. The relative success of seeding from different species was discussed, but omitted was the notion that we are now seeding with phenotypes, genotypes and species that may or may not be adapted to the climate of the last twenty years, much less the next twenty. For this, we’ll need better statistical and mechanistic models of species distributions and climatic tolerances.

One of the unsung applications of the developing USA-National Phenology Network (www.usanpn.org) is the integration of phenological data and models with climate model predictions to support societal adaptation to climate change. There are many applications, from managing allergies to agricultural production under new climates. An obvious application is the selection of mixes of species and genotypes suitable for replanting after large-scale ecological disturbances, hedging our bets and taking into account the range of predictions for changes in the onset of spring and length of the growing season. Phenology represents the evolutionary adaptation of the organism to the environment, and affects the fitness of the individual, which modulates reproductive success and survival. Ecosystem change is often about species with attributes that are important for ecosystem structure and function, and we should plant these species after disturbances rather than leave it up to successional processes, sweepstakes dispersal and random plant migration to determine the outcomes.