Chapter 6—Summary and Recommendations

In this document, much of what is understood about thresholds of ecological change is reviewed and summarized. This is a nascent field of inquiry and even the definition of thresholds remains somewhat fluid. Chapter 2 provides a clarification and should help focus future research on this topic.

Summary

The existence of thresholds in the tolerance of ecosystems to climate change should be a key concern of scientists, Federal land managers and other natural resource professionals responsible for the state of national natural resources and the ecological services they provide. Sudden, large-scale changes in ecosystems may present new challenges to resource managers because the capacity to predict, manage and adapt to threshold crossings is currently limited. One goal of resource management is to minimize variance in ecological goods and services but thresholds, as described in this document in Chapter 3, can greatly increase variance. There are numerous other implications of ecosystems crossing response thresholds because the current regulatory and legal frameworks do not account for threshold behavior of systems at present.

Recommendations

Given the knowledge that ecological thresholds exist and the lack of tools to know just where those thresholds are, scientists need to provide better predictive capabilities and managers must make adjustments to increase their capacity to cope with surprises. If climate change is pushing more ecosystems toward thresholds, what can be done at the national level? The SAP 4.2 committee identified potential actions below.

These are organized by actions or approaches that can be taken before, during, and after thresholds of ecological change are crossed.

Before

Develop Better Threshold Knowledge.—While conceptually robust and widely acknowledged, further advancement and agreement on thresholds of change in ecosystems is limited by the small number of empirical studies addressing this topic. Further advancement will be dependent on rigorous statistical testing for reliable identification of thresholds across different systems and should be a national priority because of the potential for substantive surprises in the management of our natural resources.

Monitor Multiple Drivers.—Consideration should be given to monitoring indicators of ecosystem stress rather than solely the resources and ecological services of management interest. Monitoring the effects on vegetation in coastal wetlands due to increased salinity and/or inundation from sea level rise may be able to predict what degree of stress vegetation can endure before it goes beyond the ability to recover (Burkett *et al.*, 2005). Monitoring soil conditions in areas that are susceptible to nonnative species invasions may provide information on when invasive species may appear in a stressed ecosystem and push it to its threshold. Another variation on this theme is to monitor variability rather than mean values of an ecological service. If the amplitude of variability is increasing, this trend is likely an indication of system instability before a threshold is crossed.

Collate and Integrate Information Better at Different Scales.— Greater efficiency and use of information is likely to result from coordinating and pooling information from adjoining jurisdictions and different agencies. For example, trends may not be significant or noticeable at small scales but are clear at larger scales. These and other observations argue for much better integration and coordination of monitoring information, not necessarily more monitoring. Although there is a considerable investment in making monitoring "smarter" initially, the payoff is clear in being able to detect early indicators of ecosystem change that may result in crossing thresholds.

Reduce Other Stressors.—The trigger points for abrupt change in ecosystems that are responding to climate change are rarely known because human civilizations have not witnessed climate change of this magnitude. However, an approach that is likely to reduce the threat of crossing thresholds is to reduce other stressors on ecosystems (Scott and Lemieux, 2005). These other stressors might include air and water pollution, regional landscape fragmentation, and control of invasive plants. To help reduce stressors, decisions could be made to allow larger or more extensive buffers when considering carrying capacity of habitats, minimum habitat sizes for species of interest, or use of ecological services such as water.

During

Manage Threshold Shifts.—There may be constraints to reducing or reversing climate change-induced stresses to components of an ecosystem. If a threshold seems likely to occur but the uncertainties remain high as to when it will occur, contingency plans should be created. These can be implemented when the threshold shift begins to occur or can be carried out in advance if the threshold is clear. An example is a riverine system that experiences an upward trend in water temperature due to climate change and for which no options exist for mitigating the rising temperatures. Fish species that cannot tolerate water temperatures above a threshold would have to be moved to another river system or replaced with genotypes or species tolerant of warmer water.

Project Impacts to Water Supply, Biodiversity, and Resource Extraction.—There are many efforts to project climate change (*e.g.*, GCMs) and ecosystem responses to climate change (*e.g.*, mapped atmosphere-plant-soil systems) using simulating modeling and other tools. These models generally project ecosystem trends and shifts, but do not explicitly consider the possibility of thresholds within the system dynamics of the modeling. A concerted effort must be made to understand, model, and project ecosystem responses to climate change with explicit acknowledgment of thresholds. An example is the bark beetle outbreak occurring in western forests where one threshold was passed when warmer winters allowed two life cycles of beetle reproduction per year rather than one and where a second threshold may be passed by the expansion of the forests northward to connect with boreal forests that provide a corridor eastward. Such a scenario would lead to continental scale beetle infestation (Logan *et al.*, 1998).

Recognize Need for Subcontinental Decisionmaking.— The scale of some threshold crossings, such as the bark beetle example above, is likely to require coordinated decisions on larger scales than in the past.

Instigate Institutional Change To Increase Adaptive Capacity.— The capacity for synthesis will be critical for identifying potential thresholds in ecosystem processes on multiple scales. Institutional changes that promote greater interdisciplinary and interagency scientific and information exchange are likely to increase adaptive capacity in general. The institutional changes are especially needed to implement comprehensive monitoring to detect and document responses to thresholds in ecosystems.

Identify Recommendations for Monitoring and Research.— This effort can evaluate the need for specific calls for urgently needed research to address thresholds. The ubiquity of threshold problems across so many fields suggests the possibility of finding common principles at work. The cross-cutting nature of the problem of large-scale system change suggests an unusual opportunity to leverage effort from other fields and apply it to investigating systemic risk of crossing thresholds. Ecological and economic systems share common elements as complex adaptive systems. To the extent that the analogy holds, these two disciplines have potential for mutual leverage. Beyond the specific analogy between ecology and economics, certain dynamic behaviors and structural (topological network) constraints are common to broad classes of systems. Leverage can also occur by sharing methods across disciplines. Diverse fields such as engineering risk analysis, epidemiology, and ecology employ similar methods and research styles. The aim is not to replace conventional approaches, but to explore complementary approaches. Exploiting commonalities is one way that leverage is achieved.

After

Although many of the management responses to thresholds should continue after thresholds have been crossed (e.g. monitoring, building ecosystem resilience), human society will largely be faced with adjusting to different ecosystems. These adaptations may be expensive, requiring significant new infrastructure. Capacity building, scenario planning, and adaptive management must all be applied to quickly improve the ability of management to cope with a different ecosystem and for stakeholders to adjust their expectations of ecosystem services.

Despite the incomplete understanding of thresholds of ecological change and the relative inability to predict when and where they will occur, there have been enough occurrences with significant consequences to warrant consideration of thresholds in natural resource planning and management.   This document has summarized much of what is known about thresholds and has suggested approaches to improve our understanding of thresholds, to reduce the chances of threshold crossing, and to enhance the ability to cope with thresholds that have occurred. Given the magnitude of climate change effects on ecosystems, the added factor of sudden, threshold changes complicates societal responses and underscores the importance of continued integration of research and management to develop appropriate strategies for coping with thresholds.