Transitions and Thresholds: Influences and Implications for Management in Pinyon and Juniper Woodlands

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Abstract—Thresholds are important to understanding Great Basin ecology. Once a threshold has been crossed, the new community may have very different functional capabilities than the previous community. Management action needs to occur well before a threshold is crossed to be effective, and that action needs to reflect the scales of time and space in which the affected ecosystems and their thresholds function. Great Basin woodlands have at least three categories of thresholds, with two stages in the threshold process. The three categories of threshold differ in both the duration and timing by which the two stages of the threshold process occur. Depending on the community, more than one threshold may be involved in affecting community change at the same time. Thresholds interact between communities on landscape scales over the long term, often in response to climate change, and are most effectively managed on a landscape basis.

One of the most important aspects in understanding Great Basin pinyon-juniper woodland ecology is the concept of a threshold. The basic description of a threshold is a significant change in the species composition or functioning of the community found on a site that usually results from some level of disturbance. In the majority of instances, once the change has occurred returning the community back across the threshold may be very difficult or impossible (Laycock 1991; Tausch and others 1993; Westoby and others 1989). The community that is present after the threshold has been crossed is usually a new community that could have different functional capabilities than the previous community.

If a threshold is crossed managers must recognize, evaluate, and manage the new community based on its new range of functional possibilities (Tausch 1996). They also need to look at thresholds and their outcomes in time scales appropriate to ecosystems involved (Millar 1997). Techniques need to be developed to make it possible to recognize when a threshold is being approached well before it is crossed—when some form of corrective action may still possible to avoid the coming changes.

The prevailing climate is the primary influence on the ecosystem distribution and dynamics of a region (Betancourt and others 1993; Bailey and others 1994). Climate, its changes, and its modification by landform, probably plays major roles in the development and activation of thresholds. Climate and communities have interactions, including thresholds, that occur at many spatial and temporal scales.

In response to the past climate changes Great Basin vegetation has had repeated changes (Nowak and others 1994a,b; Thompson 1990), many probably involving thresholds. The dynamic and individualistic responses to climate change by plant species (Tausch and others 1993) may be involved in the existence and outcomes of thresholds. The threshold concept needs clarification and expansion in its application to pinyon-juniper woodland ecology. Such application of the threshold concept needs to better reflect the scales of time and space and associated changes in which ecosystems function. Most examples of thresholds published (Laycock 1991; Tausch and others 1993; Westoby and others 1989) focus mostly on the biotic aspects of the changes to vegetation that result from chronic disturbances. Abiotic changes that are discussed are generally those that are evident after the vegetation has been pushed across a threshold. An expanded view is that thresholds can have both abiotic and biotic aspects, with varying levels of interaction between them.

Thresholds in Great Basin Vegetation

For the woodlands of the Great Basin, there are at least three categories of thresholds that can be described. There are also two stages to the process for each of the threshold categories: (1) crossed or set, and (2) activated. There is also a quasi third stage (dormant) that can precede any of the three categories. The three categories, two stages, and one quasi category will be explained through the use of examples.

The first category of thresholds is brought about by some form of chronic impact that pushes the vegetation through a series of changes. At some point in those vegetation changes, and in the associated abiotic changes, a threshold is crossed. An analogous description is that the community is first bent until it is right at the edge of the breaking point. Then with one last push, it finally breaks. The vegetation description is that the changes resulting from an impact reaches a point where a threshold is first set, then activated, with the final vegetation changes immediately following. Here, the setting of the threshold, and its activation, occur almost simultaneously and is the type of threshold that has been most commonly recognized and discussed. This first threshold category has the criteria that a community has crossed a threshold only when the vegetation changes involved have

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largely, or entirely occurred. While this category of thresholds is present and important in the Great Basin, others are also present.

The second category of thresholds results from changes in a community that are subtle and not always obvious. These thresholds are often abiotically driven, but biotic factors may be involved. The change in composition that has occurred has its affect on the outcome of a disturbance. This threshold can be crossed without a major readily visible vegetation change immediately occurring. The vegetation change that has occurred has resulted in a community that I am defining as "set". The final vegetation change will occur after there has been some form of major disturbance, which is the trigger that activates the final vegetation change.

Although a community can appear to be unchanged without close examination, it is the type or the outcome of a disturbance, such as fire, that has been changed. The successional processes that follow the disturbance will involve new post-disturbance successional trajectories. The alteration of the community and its successional patterns may also result in the possibility of yet new forms of disturbance in the future. For this category, subtle changes in the initial floristics of a site that occur well before a disturbance may have the effect of both generating or setting a threshold and pushing the community across it. Final activation, however, only occurs after a disturbance.

A good example of this second category of threshold is the invasion of cheatgrass into a woodland site. Woodland dynamics largely remain unchanged, even with cheatgrass in the community, as long as there is no fire. However, if the site becomes dominated by cheatgrass and other annuals following the fire, then a threshold was crossed with the cheatgrass invasion. Following fire the woodland may have been lost, which is a very different outcome than would have occurred without the presence of cheatgrass.

The invasion or establishment of any new species into a community often involves the potential for new thresholds, particularly when they develop a dominant position in the community. A threshold should be considered to be present, and to have been crossed, whenever the amount of time passing between its being set or crossed, and its activation by a disturbance, does not change the outcome. Many Great Basin communities have probably already crossed such a threshold, but the full affect of introduced or other species that are responsible is as yet unknown. The outcomes of these introductions on the generation and activation of new thresholds can be expected to play out for some time.

The third category of thresholds recognizable in Great Basin woodlands is actually quite common, but these thresholds are even more infrequently recognized as such. For this category, there is some combination of biotic and abiotic factors that both set, and then activated, the threshold. The vegetation change that results is a permanent alteration in the successional dynamics of the community. However, this activation phase may take decades to reach completion. The alteration of the successional dynamics activates the progression to a new community. This type of permanent change in the successional trajectory of a community should be considered just as much the crossing of a threshold as the other examples, even though it may take a century or more for the full change of the activation stage to manifest itself.

The third category of threshold has similarities to the first category; the main exception is that the activation phase takes much longer. They may possibly represent opposite ends of a sort of a gradient of activation patterns and rates.

The majority of the woodlands in the Great Basin may have already crossed a threshold in this third category. In the late 19^{th} century, at the end of the Little Ice Age, a series of changes occurred that generated an example of this threshold. Four of these changes were a reduction in fire frequencies (Gruell, this proceedings), heavy livestock grazing, the increase in atmospheric CO_2 (Farquhar 1997; Polley and others 1996; Tausch and others 1993) and a changing climate since the end of the Little Ice Age (Chambers and others 1998; Woolfenden 1996). Whatever the interaction of these factors, and any others that may have been involved, the majority of the potential woodland area in the Great Basin crossed a category three threshold. The outcome of this threshold has been the dramatic increase in the area and dominance of pinyon-juniper woodlands that has been progressing largely unrestricted over the last 150 years. Abiotic conditions and associated patterns of disturbance and succession that prevented this in the past are gone.

Both the second and third category thresholds may also be generated by the loss of key species. An example would be the loss of species of mycorrhizal fungi usually associated with a shrub-grass dominated community from increasing tree dominance, possibly in combination with crown fire (Klopatek and others 1988).

There is one more quasi stage, or possibly a fourth category, of proto or dormant threshold. This is a threshold that does not yet exist but most of the required precursors are in place, and if certain future dynamics occur, the threshold could potentially develop the remaining precursors to be set or crossed, and activated. History shows us that each change in vegetation sets up the conditions that interact with environmental changes to eventually trigger the next set of vegetation changes (Tausch, this proceedings). The examples of the woodland expansion, the introduction of annuals, and ongoing climate change described are causing community changes that are setting up the conditions for the eventual development of additional new thresholds. The potential for there to be new community patterns after these thresholds are crossed is high, particularly where exotic annuals are involved.

A community dominated by exotic annuals is essentially an open or unstable community waiting for the next invader. This is an example that represents a dormant threshold that cannot be generated, or set and activated, until after the arrival of the next species capable of invading the site. This invasion will happen, we just do not know when or what the species or the outcome will be until it happens. The community changes associated with the dominance of annuals is also leading to unknown changes in nutrient cycles and microbial processes for the sites and communities involved (Klopatek and others 1988). These soil changes could also contribute to the future development of new thresholds.

A second example of a dormant threshold is also present in many of the current woodlands that crossed the third category of threshold at the end of the Little ice Age. The altered successional changes that resulted are moving the woodlands toward yet another threshold. As larger and larger areas of these woodlands reach the point of crown closure, thereby becoming susceptible to catastrophic crown fire, they will have reached and then crossed a second formerly dormant category two threshold. The permanent vegetation changes will then wait only for the disturbance.

There appear to be two general ways environmental influences can bring any of these thresholds into existence—direct and indirect. The direct effects are most commonly reported in the literature and are usually involved with the first category of threshold. A disturbance directly impacts the vegetation, and the changes brought about pushes the community toward, and finally over, the threshold. Direct effects can work through biotic or abiotic mechanisms, may or may not be the final trigger activating the vegetation change.

Indirect effects appear to usually result from abiotic changes. An example of indirect effects is the fertilization effects of increasing atmospheric CO_2 and the differing responses to this increase between plant species (Farquhar 1997; Polley and others 1996). In many communities this indirect effect represents at least the presence of possible dormant thresholds. We do not know how each community is being affected, what thresholds are pending or already crossed, and what the resulting vegetation changes will be.

More than one threshold can also be involved at one time. As previously explained, Great Basin woodlands crossed a third category threshold in the late 19^{th} century. The activation stage of that threshold is still underway. On some sites there has been the introduction of cheatgrass, which has taken these sites across the second category of threshold. As the successional processes from the activation stage of the first threshold run their course, the dormant biotic threshold of susceptibility to catastrophic crown fire will be reached and set. When the next activation stage is triggered by fire, the outcome will be much different for many sites than if the cheatgrass were absent. Unless something changes the communities to alter those trajectories of change and their associated thresholds, the final activation by fire and conversion to an annual-dominated community will only be a matter of time.

Scale-related factors are important in defining ecosystem boundaries and the associated development and outcomes of thresholds. Interaction between regional and local scale topography, soils, associated species, environmental conditions, and disturbance types and frequencies can also cause major changes in the way sites respond to a disturbance, and thus affect both the presence and outcomes of thresholds. At each level in the nested structure of Great Basin ecosystems, a different aspect of climate and vegetation can be important in the development of thresholds.

How any system responds to the development and activation of thresholds is also at least partially related to how it interacts with surrounding systems. Changes occurring in other communities in the area around a particular community can result in the generation of a threshold, even if that community has had no change, for example a woodland on a steep slope with shallow soils. When the community on an adjacent site with deeper soils was non tree-dominated, fire intensity was insufficient to carry up through the woodland. If the adjacent community becomes tree-dominated, the heat generated by the next fire will be sufficient for the fire to carry up through the woodland on the adjacent slope.

Because of the environmental and topographic heterogeneity of the Great Basin, communities generally do not develop toward new thresholds at the same rate across a landscape. The thresholds that develop can differ from location to location, which may help prevent the simultaneous occurrence of the same change over a large area.

Over time, topographic-based site-to-site differences may have a tendency to break up large areas of uniform vegetation. An example of such an outcome is the high level of vegetation heterogeneity in chaparral in northern Baja, Mexico (Minnich and Chou 1997). As the areas experiencing a particular change become smaller, the mix of vegetation types and their associated successional stages may become more heterogenous over the landscape. The intermixing and interfingering of the mix of communities and associated successional stages that can develop increases landscape complexity. One way of describing it would be a dynamic fractal-like distribution across the landscape that is constantly changing. The outcome of thresholds becomes spatially more limited.

The pattern through history is that some environmental conditions seem to increase the development of landscape heterogeneity or complexity, and others seem to decrease it. There is an apparent shifting back and forth between community patterns of uniformity, or of more complexity. There appears to be some relationship between the types of community patterns present, the types and severity of the climatic changes, the associated disturbances involved, and the level of heterogeneity or homogeneity.

Management Implications

We know from history that the processes of change always continue through time (Nowak and others 1994a,b; Tausch and others 1993; Woolfenden 1996). Any of these changes in conditions can introduce new thresholds. Ecosystem management is the management of these changes and their associated thresholds as they are mixed over the landscape. Through management actions, we can slow or accelerate the trajectories of change, we can alter their direction, sometimes even reverse them, but we can never stop them. Every alteration we make, however, will affect the type, timing, magnitude, interaction, and outcome of future thresholds. The more effectively we can anticipate these changes resulting from our actions, the more effective ecosystem management will be.

If vegetation that has crossed a second or third category of threshold is not altered by direct intervention to change its structure or composition, the activation of the threshold by a disturbance will only be a matter of time. It will be desirable to attempt to treat some of these areas to possibly alter the outcome, which may or may not be easier to do before the activation stage has occurred. These treatments should be done based on the conditions existing on the entire associated landscape to maintain the diversity of the community, its successional stages, and their interconnectedness, and to help avoid the establishment of new, unwanted thresholds. The treatments used must incorporate the biological, topographic, and edaphic heterogeneity of the sites involved into their application. This is to preserve, and to take advantage of, the existing diversity—both biotic and abiotic.

Most of the existing treatments that have occurred so far in Great Basin woodlands have been, at least indirectly, and even if unknowingly, attempting to prevent the activation of, or alter the existence of, one or more of the described thresholds. Most the these treatments, such as chaining, have tended to ignore the biological, topographic, and edaphic heterogeneity of the treated sites. Usually they have been based more on a plowed-field type of model in their application. Large blocks have been treated as uniformly as possible over their entirety. Either no place within the treatment area is left unaffected, or a few token untreated islands are left isolated within the treatment. Also, on most of the acres that have been treated, the results are often inadequate. These treatments have sometimes provided a short-term slowing of the generation or activation of the targeted threshold. They have largely not changed the final outcome because they have not been based on the dynamics of the target communities and their thresholds.

The current level of uniformity over many areas of Great Basin woodlands may be one of the highest of the Holocene (Tausch, this proceedings). This uniformity appears to be the result of human activities over the last century and a half that have interacted with climate change to contribute to the simplification and homogenization of the landscape. It is basically the same outcome as observed in southern California chaparral where management activities have greatly increased their homogeneity in comparison to the chaparral across the border in northern Baja, Mexico (Minnich and Chou 1997). This homogenization has resulted from several impacts, including the introduction of exotic annuals, the many types of natural resource utilization patterns, fire suppression efforts, and the related increasing dominance of woody species. The increasing CO_2 content of the atmosphere, and atmospheric input of nitrogen into the system from air pollution, could also be contributing components. Such simplified, homogenized systems can be prone to the development of new thresholds. These thresholds can precipitate major vegetation and system changes that are new, or unique, to the ecosystems and species affected. Because of the homogeneity the changes can affect large areas simultaneously.

Past management activities have tended to apply similar procedures across the landscape on a piecemeal basis without adequate consideration of landscape variability or long-term consequences. As in other regions, this narrow focus has often contributed to ecosystem homogenization over large areas of the Great Basin. Such piecemeal management has also tended to have limited long-term success. Correcting these problems will require closer observation within the context of the greater temporal and spatial scales within which each site is imbedded. Unless such landscape level dynamics, and their long-term changes and interactions with thresholds, are a part of future ecosystem management, success will remain limited.

Identification of the controlling environmental factors is necessary to manage thresholds on the basis of landscape-level interactions over the long-term. For the Great Basin, much of the needed information on factors controlling community dynamics is absent. Additionally, different combinations of controlling factors can, in different locations, result in similar- appearing vegetation communities. These communities may have different thresholds and may respond differently to the same management or disturbance despite their similar appearance. Because our knowledge of causes is limited, we have often been left with only descriptions of the differences these causes have produced (Bailey and others 1994). The need to move beyond describing the outcomes after they have occurred, to being able to anticipate future changes, is probably our greatest challenge.

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