DISTURBANCE MANAGEMENT - APPLICATION OF ECOLOGICAL KNOWLEDGE TO HABITAT RESTORATION

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Summary

Disturbance plays a roll in ecology so important that it is arguably the cause, condition, and solution to conservation measures. Discrete disturbances are described in many spatial and temporal terms, but their importance to ecological systems is dependant on their timing during succession. Understanding this dynamic role is the task of restorationists who need to know that ecosystems evolve to be resilient to a particular set of historical disturbances.

This historical precedence can show restoration managers the typical kinds of disturbances that are natural to the patch or multi-patch system in question. The application of the appropriate disturbance at a key moment can steer the system towards dynamic equilibrium. It is disturbance regimes that act as filter and strain non-resilient organisms from those communities. Conservationists must recognize the importance of these discrete processes and learn to include them in sound restoration practices.

Here, I first introduce concepts and theory relating disturbance ecology to restoration

(Part A), then discuss for practitioners ways of applying ecological knowledge to restoration challenges (Part B), and finally present a case study substituting missing dynamics on former military training areas in central Europe by conservation action (Part C).

1. Part A: Concepts and theory - relating disturbance ecology to restoration

1.1 The general role of disturbance in restoration

Restoration ecologists and managers are increasingly challenged to restore ecological processes that lead to self-sustaining ecosystem dynamics. Due to changing environmental conditions, however, restoration goals need to include novel regimes beyond prior reference conditions. In the restoration process, disturbance ecology offers crucial insights into the driving forces of ecosystem dynamics. Moreover, restoration efforts can make efficient use of natural or human disturbance regimes in the re-establishment of ecosystem dynamics, such as in novel grazing regimes on abandoned pasture lands (e.g. Lindborg & Eriksson 2004), increased flooding dynamics in riparian ecosystems (Moerke & Lambertio 2004), mechanical ground disturbances in temperate dry acidic grasslands on former military training areas (e.g. Jentsch & Beyschlag 2003, Jentsch et al. 2007), and prescribed burning in boreal forests (Fule et al. 2004).

Modifying ecosystem dynamics for restoration purposes can be done effectively by using disturbance as a management tool, for instance, to set back the successional clock or alter the filter restrictions for species establishment and community assembly. Natural disturbance events can additionally be used as a ‘window of opportunity’ for restoration purposes, such as enhancing plant establishment after heavy rainfalls associated with El Nino in arid environments (Holmgren et al. 2006). Thus, restoration managers have two different options for modifying ecosystem dynamics at restoration sites; manipulating continuous processes (succession) or making use of discrete events (disturbance).

1.2 Continuous versus discrete processes in ecosystem dynamics

Temporal dynamics in ecosystems are the product of two interacting factors, continuous and discrete processes (Hobbs et al. 2006). Continuous processes include gradual accumulation of biomass and nutrients as the system moves through progressive successional stages. Discrete processes include the occurrence of disturbance, which can cause rapid transitions between different ecosystem states or suddenly reset the successional clock. In addition, a disturbance can change continuous processes such as colonization or extinction of indigenous species and sudden events such as rapid invasion of an alien species.

Experience in restoration projects has repeatedly shown, however, that the story of successional direction is complex, particularly in a world experiencing drastic changes in disturbance regimes (Jentsch and Beierkuhnlein 2003, Aronson and Vallejo 2006). Disturbance and its interactive effects on species colonization and extinction potential are a vital part of the dynamics of ecosystem development. Disturbance regimes, including intensity and frequency of disturbance events, are recognized as critical drivers of successional trajectories (White and Jentsch 2001). This is partly due to disturbances varying in intensity and severity and accordingly in ecosystem legacy. Natural and anthropogenic disturbances produce a continuum of conditions between extremes termed primary and secondary succession, which differ in the legacies that remain from the pre-disturbance ecosystem. The amount and distribution of organic matter, the presence and life histories of living organisms, and soil properties all affect the recovery mode and rate. The main reasons for the restoration of an ecosystem are usually created by anthropogenic and natural disturbances.

1.3 Significance of disturbance for ecosystem dynamics

Disturbance is essential to the survival of many species (Walker et al. 1999). Disturbances are ubiquitous, inherent and unavoidable, affecting all levels of biological organization. Ecosystems are influenced by disturbances of various kinds, such as fires, windstorms, landslides, flooding, logging, grazing, burrowing animals and outbreaks of pathogens. Due to natural and anthropogenic disturbances, ecosystems undergo changes that are sudden or gradual, dramatic or subtle.

The presence of disturbances in all ecosystems, their occurrence at a wide range of spatial and temporal scales, and their continuity across all levels of ecological organization is the essence of their importance (White & Jentsch 2001). Together, succession, assembly and disturbance theory deal with the processes by which the living components of an ecosystem change over time and how the species assemblage present at any one time may be explained (Hobbs et al. 2006). Thus, understanding the relation between succession, assembly and disturbance helps restoration managers to analyse current ecosystem dynamics at restoration sites and to assess impacts of restoration action on future ecosystem trajectory.

Organizing disturbances along two spatial (patch and multi-patch) and two temporal (event and multi-event) categories can help restoration ecologists to classify insights from disturbance ecology and to derive options for disturbance management. Here, the patch and multi-patch concept and its implications are introduced after stating definitional issues.

1.4 Disturbance definition

According to Pickett and White (1985), disturbance is defined in a neutral way as a discrete event in time that disrupts the ecosystem, community or population structure, and changes the resources, substrate availability or the physical environment. Disturbance descriptors are used to characterize individual disturbances and to describe disturbance regimes. These descriptors include:

- Temporal characteristics (such as frequency, duration, and seasonality),
- Spatial characteristics (such as patch size, shape, and distribution),
- Magnitude (or intensity),
- Specificity (to species, size, or age classes),
- Synergisms (disturbance interactions and feedbacks; white et al. 1999). A

disturbance regime is the sum of all disturbances affecting an ecosystem. Disturbance in a restoration context is far more than just the event which creates the degradation or change of state. Disturbance can be an essential tool of management action during the restoration process itself, because it can modify ecosystem dynamics. Additionally, disturbance regimes, or the mix of different disturbances characterised by their size, frequency and intensity, need to be restored as such, because they play a crucial role in dynamics of restored sites in many ecosystems (jentsch 2006, warren et al. 2007).

1.5 The patch and multi-patch concept

Disturbances are highly variable in kind, cause, and effect. They act across spatial and functional scales, and influence ecosystem composition and structure long after their brief duration of occurrence (White and Jentsch 2001). To understand and restore dynamics in ecosystems prone to disturbance, it is necessary to measure conditions within individual patches, such as species composition, resource availability, the legacy of the pre-disturbance ecosystem, and the degree of heterogeneity produced. These factors influence ecosystem response. It is further necessary to describe the site quality relative to landscape trajectory. Restoration can focus on whether within or between patch dynamics have been initiated. Restoration ecologists can assess whether dynamic equilibrium is maintained despite or due to disturbance, whether restoration action is targeted at sustaining or counteracting ongoing disturbance dynamics.

To understand this diversity in disturbances and responses, restoration managers need a general structure for organizing disturbances along spatial and temporal scales (Table 1): the patch and multi-patch concept (Jentsch et al. 2002a).

Space / Time	**Event**	**Multi-Event**
Patch (disturbance)	P – E	P – ME
Multi-Patch (landscape)	MP – E	MP – ME

Table 1: Organizing insights from disturbance ecology in four categories: (1) “patch – event”, (2) “patch – multi-event”, (3) “multi-patch – event”, and (4) “multi-patch – multi-event”. All findings can be organized in two spatial and two temporal dimensions. Examples: (1) one discrete fire event in a forest stand, (2) recurrent flooding dynamics in a particular river section, (3) spatially heterogeneous outbreak of an insect pest in a particular year, and (4) mowing regime in a cultural landscape (from Hobbs et al. 2006)

The “patch scale” is the spatial extent and period in time of a patch being affected by a particular disturbance. Disturbances may destroy biomass, homogenize plant species composition, disorganize established patterns of competition, or initiate primary succession (Walker & del Moral 2003). Within such a patch, three questions arise: first, is the process under consideration related to stress or to disturbance? While a stressor, such as enhanced UV-radiation due to higher elevation, is a continuous process, a disturbance, such as a fire event, is abrupt and discrete in time relative to the life span of the affected organisms (White & Jentsch 2001). Both forces have different implications for assembly rules and ecosystem trajectory, and thus to restoration action. Second, which ecological legacy survived the intensity of the disturbance event? The answer to this question influences recovery in terms of nutrient availability, seed survival, and heterogeneity of micro-site conditions. These determine restoration actions such as assisted recovery. Third, in which way has the disturbance event modified resource availability? Restoration actions can establish the target level of productivity, add species appropriate to conditions, use disturbance to remove inhibition, increase resources, and create turnover to accelerate, decelerate, or halt succession if appropriate (White & Jentsch 2004, Hobbs et al. 2006). Properties within a patch are dependent on the properties of the surrounding patches, because patches are connected by interactions.

At the “multi-patch scale”, meaning aggregates of disturbed and undisturbed patches, the focus is on patch interactions, biodiversity, and system dynamics. Here, disturbance may reorganize system structure or drive and stabilize pattern dynamics.

- First, does the current disturbance regime have historical precedence so that there are functional traits present to cope with it, and the presence of disturbance dependent species is supported? Restoration actions should seek to understand the long-term event regime and to understand the requirements of the target species that sustain ecosystem dynamics (Beierkuhnlein & Jentsch 2005).
- Second, is there specificity in the disturbance regime? Specificity can modify succession by selecting for species, growth forms, or functional traits. Restoration actions introduce disturbance at the right stage of successional turnover in order to accelerate or arrest succession or produce episodic reproduction in target species.
- Third, what is the disturbance architecture (Moloney & Levin 1996)? The greater the spatial heterogeneity of disturbance, the greater the species diversity of the site is. The higher the frequency of disturbance is, the greater the selection for early reproduction and fast growing species. Restoration actions can establish the disturbance specificity, frequency, and spatial pattern which will promote the desired composition and structure (White & Jentsch 2004).
- Moloney and Levin (1996) have suggested that the concept of disturbance regimes be organized according to a three- level architecture:
- Non-spatial components: rate and intensity of disturbance. The rate of disturbance determines the immediate impact of a disturbance regime on the plant community or ecological landscape (the proportion of space changed to a different successional state). The disturbance intensity determines how the disturbance interacts with species' life-history attributes (which defines the new successional state after disturbance). The general decrease in overall plant density with an increasing overall disturbance rate is an effect that involves the trade-off between disturbance-induced mortality and the ability to re-colonize new disturbance-created sites. The disturbance intensity determines the functional groups to which that disturbance provides additional establishment sites (this is also dependent on competitive ability and seed availability).
- Spatial components: size and shape of individual disturbances. The size, shape and correlating structures among individual disturbances determine the rate at which disturbed sites can be re-colonized (depending on the species' life-history characteristics) and eventually determine the structure of the landscape mosaic.
- Spatio-temporal components of groups of disturbances: spatial and temporal auto-correlation among individual disturbances.

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Biographical Sketch

Anke Jentsch, born 1971 in Frankfurt a. Main, Germany, studied Biology at the University of Erlangen-Nürnberg, and Anthropology at Oglethorpe University, Atlanta, GA, USA. She obtained her Ph D. in Experimental and Systems Ecology at the University of Bielefeld, Germany. After being a post-doc researcher at the Department of Conservation Biology of the Helmholtz Centre for Environmental Research UFZ Leipzig, Germany, she became a junior professor for “Disturbance Ecology and Vegetation Dynamics” in double affiliation with the University of Bayreuth. Currently, she co-ordinates the research area “Biodiversity and Disturbance”. Her main research interest is towards generality in disturbance ecology across various ecosystems and scales. Investigations include field experiments on vegetation dynamics and pattern formation in dry acidic grasslands, on the effects of extreme weather events (drought, heavy rain, freeze-thaw cycles) on biodiversity and ecosystem functioning and on linking ecological science to restoration practice.