Agents of Pattern Formation: Disturbance Regimes

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Assigned Reading: Turner et al. 2001 (Chapter 4); Romme et al. (1995)

Objective: Provide an overview of disturbance processes (natural and anthropogenic) as agents of pattern formation. Highlight importance of disturbance interactions and feedback, including interactions with biotic processes and the physical environmental template.

Topics covered:
1. What is disturbance?
2. Characteristics of disturbances and disturbance regimes
3. Role of disturbance in ecosystems and landscapes
4. Factors affecting disturbances
5. Feedback mechanisms affecting disturbance regimes
6. Interactions among the physical template, biotic processes and disturbance regimes
7. Human effects on disturbance regimes

Comments: Some material taken from Dean Urban’s Landscape Ecology course notes
1. What is Disturbance?

Disturbance has been variously defined by ecologists, and with little consensus. Although most people have an intuitive idea of what constitutes a disturbance, precise definition can be elusive. The term perturbation is sometimes used interchangeably with disturbance, although they connote slightly different things:

- **Disturbance**—Any relatively discrete event (natural or anthropogenic) in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment, including both destructive, catastrophic events as well as less notable, natural environmental fluctuations. Typically, a disturbance causes a significant change in the system under consideration (White and Pickett 1985).

- **Perturbation**—A change in a parameter (state variable) that defines a system; that is, a departure (explicitly defined) from a normal state, behavior, or trajectory (also explicitly defined).
The key parts of this definition are that disturbances are discrete in time, in contrast to chronic stress or background environmental variability; and that they cause a notable change (a perturbation) in the state of the system.

Are disturbances a part of the system itself? Are they "inside" or "outside" the system? These are some of the issues that have confused discussions about disturbance in the past. As we shall see, it depends on your frame of reference. Allen and Wyleto (1983) described a fire-driven prairie system at two levels of reference. Using species abundances and individual fires, they characterized the successional response to fire. At this level, a single fire is 'outside' the system and plant species respond to a fire as an extrinsic driver. Aggregating fires into a multi-year fire frequency and collapsing species abundances to presence/absence, they characterized the species assemblages induced by various fire frequencies. At this level, fire is 'inside' the system. That, is changing the nature of the observations also changes the role of the disturbance as being extrinsic or intrinsic to the system. In general, a disturbance at one scale implies a larger scale that would stabilize it (sensu Watt's unit pattern). Much of our interest in disturbance regimes will revolve around characterizing the spatiotemporal scaling of disturbance regimes, and considering the implications of this scaling for understanding natural and managed systems.
2. Characteristics of Disturbances and Disturbance Regimes

Disturbances can be characterized in a variety of ways, and these attributes collectively describe and characterize a disturbance regime.

- **Area/Size**—The areal extent of the disturbances, including the size of disturbance patches; the area per event per time period, and the total area per disturbance per time period.

- **Spatial distribution**—The spatial distribution of the disturbance; that is, the distribution of events relative to topography, soils, and so on. This typically would also impart or reinforce a characteristic spatial scale as well. This would include contagion -- tendency to, and rate of spread, and factors affecting the dispersion of the event.

- **Frequency**—The mean number of disturbance events per time period within a specified area. This is perhaps one of the most commonly reported attributes of a disturbance regime.

- **Recurrence Interval**—The mean time between disturbance events within a specified area. This is equal to the inverse of the disturbance frequency.
• **Return Interval**.—The mean time between disturbance events at the same location; that is, how frequently is the same spot of ground disturbed. This is a critical component of the disturbance regime because it directly affects the amount of time the ecosystem, community, or population has to recover (e.g., as in succession) before the next disturbance.

• **Rotation Period**.—The mean time to cumulatively disturb an area equivalent to the entire study area. In other words, given the frequency of disturbance events and the area/size disturbed by each event, how long does it take to cumulatively disturb an area equal to the size of the entire study area. Note, this is not equal to the time required to disturb every location in the study area at least once, since some areas may get disturbed many times while others may not get disturbed at all within the rotation period. Also, the rotation period is equal to the return interval and is thus simply another way to describe the same phenomenon.

• **Predictability**.—The variance associated with the recurrence or return interval and/or frequency. If the variance is low, there is high predictability concerning when an area is likely to be disturbed based on the time since last disturbance. If the variance is high, there is a lot of variation in the return interval, making it difficult to predict with any confidence when an area is likely to be disturbed.

• **Magnitude**.—There are two aspects of magnitude: **Intensity** refers to the magnitude in physical force of the event per unit area and time; **Severity** refers to the magnitude of impact on organism, community, or ecosystem.

• **Synergism**.—The effects of a disturbance event on the occurrence of other disturbances. For example, there may be a synergistic relationship between insect infestations in certain forest types and the occurrence of fire.

• **Feedbacks**.—Some disturbances either engender or constrain others. For example, fire may synchronize other subsequent fires in frequency as well as patch boundaries; reciprocally, lack of fire can reinforce a system's resistance to fire.
In addition, disturbances can be classified according to the type of disturbance agent (physical, biological, or interaction of physical and biological) and according to whether they originate from within the community/ecosystem or from outside:

- **Endogenous Causes.**—Originate from within the community/ecosystem (i.e., autogenic). For example, tree fall caused by senescence and mortality would be an endogenous disturbance.

- **Exogenous Causes.**—Originate from outside the community/ecosystem (i.e., allogenic). For example, fire and hurricane-induced wind-throw would be exogenous disturbances.
Classical “disturbance” is a special case on a continuum with respect to the cause of the disturbance (endogenous-exogenous continuum), the relative discreteness of the event in time, the relative discreteness of the disturbance patch created, and the relative effect on ecosystem resources. The classical disturbance is the demonstratably exogenous disturbance that acts at a single point in time, creates abrupt patch boundaries, and increases resource availability through decreased biological use of resources or increased decomposition or both. Classical disturbance acts to “reset” the successional clock of the ecosystem without influencing the ultimate, predictable trajectory or that change or the potential biomass supportable on that site.
Disturbance regimes include disturbances (i.e., events) at many intensities and scales, from the death of a single dominant tree to a catastrophic forest fire to volcanic eruptions and impacts by comets, all of which are embedded within climatic cycles that may span decades to millions of years.

- The disturbance regime of a particular forest usually consists of a complex mixture of infrequent, large-scale events (e.g., a large fire or windstorm) and more frequent, small-scale events (e.g., small fires, the fall of a single tree), each characterized in terms of the definitions above. For example, Reiners and Lang (1979) described a multilevel disturbance regime for the White Mountains in New England, consisting of strips, broken tree gaps, glades, and fir waves-- with each disturbance having its own characteristic scaling and spatial associations.
• Therefore, one might draw very different conclusions about the disturbance history of a given piece of ground depending on what time period is considered.
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Characteristics of a Disturbance Regime

- Disturbance regimes cannot be understood in isolation; they are tied to the systems to which they are linked and ultimately to events within surrounding landscapes, the region, and the globe.

- The disturbance regime of a particular ecosystem cannot be understood in isolation, but rather it is tied to the systems to which it is linked ultimately to events within surrounding landscapes, the region, and the globe.
3. Role of Disturbance in Ecosystems and Landscapes

Ecosystems and landscapes depend on “natural” disturbances:

- Natural disturbances perform critical functions (e.g., nutrient recycling) that maintain ecosystem/landscape structure and processes (e.g., initiating succession). Many forest species, for example, persist only because of periodic disturbances. For example, without windthrow, which exposes mineral soil seedbeds, some northern forests convert to bogs. Numerous forest types throughout the globe are maintained by periodic fire.

- All ecosystems have a “natural” disturbance regime to which they are adapted evolutionarily and, in certain cases, can maintain integrity despite dramatic large-scale disturbance events.

- Disturbance plays a key role in ecosystem and landscape dynamics; specifically, in initiating secondary succession and maintaining ecosystems in a constant state of flux.

- In many landscapes, coarse-scale disturbances generate the patch mosaic structure that constitutes the dominant patterns in the distribution of vegetation. Such disturbance-dominated landscape have a patch mosaic structure and patch dynamics that governs the abundance and distribution of many species and communities.
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Role of “Natural” Disturbances

- Phase-state diagram for forest succession!

Unlikely path (fireproof)

Likely path
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Role of “Natural” Disturbances

- The disturbance-generated mosaic

Fire (Yellowstone National Park)

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Role of “Natural” Disturbances

- The disturbance-generated mosaic

Tornado (Tionesta Scenic Area) (1985)

Hurricane 1938 (New England)

Flood (Mississippi River) (1993)
Exotic disturbances (types and regimes), however, often disrupt system integrity and cause the system to move to another multiple states operating range. For example, large-scale logging and burning in tropical forests causes relatively permanent state changes in the ecosystem/landscape.
4. Factors Affecting Disturbance Regimes

There are numerous factors affecting disturbance regimes:

- Macroclimatic patterns, especially global climate patterns, are often the ultimate regulatory factors in establishing disturbance regimes.

- Regional and local patterns of topography, soils, and vegetation can also play a critical role in affecting disturbance regimes.

- Distribution of people (e.g., roads, trails, communities) and their activities (e.g., firewood cutting, ORV use, camping).
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Factors Affecting Disturbance Regimes

- Regional and local patterns of topography, soils, and vegetation.

![Image](image_url)

**Figure 5.4.** Distribution of lightning fires in Great Smoky Mountains National Park as a function of elevation and site moisture gradients (from Harmon et al., 1983).

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Factors Affecting Disturbance Regimes

- Interaction of macroclimatic patterns, terrain, and vegetation.

In New England, forest damage due to hurricanes resulted from characteristics of the storm (i.e., wind direction and speed), topographic exposure, and the height and composition of vegetation (Foster et al., Boose et al.).

Boose et al. 1994

6.16
Macroclimatic patterns, terrain and vegetation interact in complex ways to affect disturbance regimes. Landscape patterns in vegetation at the local and regional level can profoundly influence species interactions, regional climates, and the propagation of disturbance.

The manner in which landscape patterns affect the spread of disturbance is quite complex. Turner and Romme (1994) suggested a model in which landscape pattern has no effect on the spread of fire when fuel moisture is high (and hence has low flammability) or when it is very low and the spread of fire is driven by wind. Only under conditions of low fuel moisture when fire is not driven by extreme winds does the landscape pattern strongly affect the spread of fire.
5. Feedback Mechanisms Affecting Disturbance Regimes

Landscapes half self-reinforcing patterns that tend to reinforce the existing structure.

- Some landscapes tend to absorb and dampen the spread of disturbances; whereas, some landscapes magnify the spread of disturbance. For example, in some forest types (e.g., Douglas-fir, ponderosa pine, and moist tropical) large intact blocks of healthy, mature forests or nondecadent, old-growth forests are less susceptible to catastrophic fires than young or fragmented forests. Landscapes dominated by these types buffer and dampen the spread of crown fires and hence preserve the forest structure. Once some threshold proportion of the landscape becomes fragmented and permeated by flammable young forests or grasses, the potential exists for a self-reinforcing cycle of catastrophic fires—an absorbing landscape crosses a threshold and becomes a magnifying one.
Landscape patterns of vegetation can have a pronounced effect on regional climate, largely through albedo (fraction of solar energy reflected back into space from the earth’s surface) and transpiration, and the relationship can be self-reinforcing. For example, the Amazon rainforest receives twice as much precipitation as can be accounted for by moisture moving in from the ocean. By transpiring and keeping water in circulation, the rainforest generates the rain that supports the forest. Deforestation in this landscape may disrupt this feedback loop, and once a threshold is crossed, the climate may be altered enough so that the remaining forests could not persist.
6. Interactions among the Physical Template, Biotic Processes and Disturbance Regimes

It should be obvious from the above that disturbance regimes do not operate independently to create landscape patterns, but rather interact with the physical template and biotic processes, often in synergistic ways, to affect landscape patterns. Indeed, in real landscapes it is exceedingly difficult to isolate the independent affects of these three agents because they are typically confounded in there effects. This fact is perhaps best illustrated by an example.

This example involves the whitebark pine ecosystem of the high elevation Rocky Mountains and a critical ecological triangle involving whitebark pines, Clarks nutcrackers and wildfire.
The first component of the triangle is whitebark pine. In the northern Rockies, whitebark grows in the upper subalpine zone up to timberline, generally between 8,000-9,500 ft elevation, where it is the dominant tree species. It has good cone crops every 3-5 years, and produces large, nutritious, fatty seeds that are used by over 110 wildlife species. Whitebark seeds are considered a critical food source for grizzly bears. The cones produce wingless seeds, the cone scales do not open, and the cones are displayed upward – all of which means it is entirely dependent on birds (and mammals) for dispersal.
The second component of the triangle is the Clarks nutcracker. This bird is the sole seed dispersal vector for whitebark pine. They disperse seeds up to 10-20 km from the parent tree. They bury 1-15 seeds about 1-2 cm deep in caches on ground. They can create 8,000 to 20,000 caches in one year. They revisits 50-80 percent of caches. Unclaimed seed is sole source of regeneration. The unclaimed seed is in fact the sole source of regeneration in this tree species, making this an obligate mutualistic relationship for the pine.
The third component of the triangle is wildfire. Wildfires are the major disturbance in whitebark pine forests, although mountain pine beetle outbreaks have also become more common in recent decades and the introduced white pine blister rust is a major source of mortality as well. The fire regime is characterized as a mixed severity fire regime, which means that it includes significant components of high severity (stand replacing) and non-lethal surface fires, with a mean return interval of 80 to 500+ years. Fire are caused by lightning and typically occur during major droughts in the driest part of summer/early fall.
The critical ecological triangle is as follows. Burned areas are rich in pattern because of the mixed severity fires that are typical. Nutcrackers like caching whitebark pine seeds in burns and open areas that are rich in pattern. Nutcrackers disperse seed great distances (>10 km). Whitebark has colonization advantage and survives well in burned sites.

Ultimately, the whitebark pine distribution is regulated by the physical environment – it occupies the upper subalpine zone. However, it also depends on fire to create seedling establishment sites and it relies on the nutcracker to disperse seeds to these favorable sites. The nutcracker in turn depends on the whitebark as a major food source. In general, fires create conditions that favor the growth of whitebark. Thus, the entire triangle is self-reinforcing; i.e., it functions to create and maintain the system. The vegetation patterns of the high elevation Rockies would not be the same without the complex interaction of whitebark pine, Clarks nutcracker and wildfire.
7. Human Effects on Disturbance Regimes

Land use practices have a variety of effects on natural disturbance regimes:

- Rescaling natural disturbance regimes by making disturbances smaller (or larger), less frequent (or more), more or less intense by altering land use or by suppressing the natural processes that maintain diversity. For example:
  - biogeographic barriers created by humans (e.g., roads, canals, park boundaries defined by radical change in habitat) can modify the spread (and thus size) of disturbances.
  - vegetation treatments designed to manipulate fuel loads and continuity can modify the frequency, size and intensity of wildfires.
  - vegetation treatments to meet timber objectives (e.g., clearcutting) can have the unintended effect of modifying the frequency of other disturbance processes such as mass soil movements (e.g., landslides).
  - livestock grazing, coupled with fire suppression, can alter fuel beds sufficiently to reduce the frequency and spread of subsequent fires, fostering the establishment and growth of abundant woody vegetation and eventually making subsequent fires more intense.
  - converting natural "old-growth" forests to managed plantations fundamentally alters the ecosystem composition and structure and can substantially modify (or eliminate altogether) the natural disturbance regime.
• Introducing novel (unprecedented) disturbances, chronic stresses, unnatural shape complexity or degrees of connectedness. For example:
  ▶ roads are perhaps the most insidious novel disturbance to natural landscapes; they can function to modify the frequency of initiation and spread of disturbances such as fire and wind and can serve as facilitated movement corridors for the invasion of non-native pests and pathogens.
  ▶ vegetation management practices, such as dispersed (or staggered setting) clearcutting, can introduce novel spatial patterns to the landscape, modifying the composition and configuration of habitats for organisms.
  ▶ humans often introduce novel disturbances such as fire to landscapes that have not evolved with fire (e.g., burning after clearing Amazonian rainforest) which can result in complete ecosystem conversion.
8. Resource Management Implications

The role of disturbance regimes in patterning landscapes has many conservation implications. These implications can be categorized in terms of responses to anthropogenic climatic change and implications for conservation planning and resource management.

8.1. Implications for Conservation Planning and Resource Management

An appreciation that disturbances can override the patterns caused by the interplay between biotic processes and the underlying physical template has tremendous implications for conservation planning; in particular, for the development of viable strategies for the conservation of biodiversity. These strategies can be classified into one of three types:

First, the planning and management strategy might be to prevent, mitigate or reduce disturbance (e.g., fuel reduction, manage landscape pattern to reduce insect outbreaks). This strategy is typically motivated by a desire to avoid or minimize the risk to people and/or property. Under this strategy managers might reduce the amount and continuity of susceptible conditions (e.g., fuels treatments, fire breaks). However, this strategy comes with the cost of reducing or eliminating the benefits of disturbance to the natural system and may exacerbate the effects of future disturbances.
Second, the planning and management strategy might be to manage with disturbance (i.e., embrace natural disturbance processes). This strategy is typically motivated by a recognition that disturbances (within their natural range of variability) enhance biodiversity. Under this strategy managers might use disturbance to create ecosystem conditions that can best absorb natural disturbances. However, this strategy comes with the cost of unexpected interactions with other parts of the system as well as commodity reduction and risks to people and property.
Lastly, the planning and management strategy might be to emulate natural disturbance. This strategy, like the last, is typically motivated by a recognition that species and communities are adapted to natural disturbance regimes and that ecosystems are more likely to be resilient to natural disturbance regimes. Under this strategy managers might use vegetation management to emulate natural disturbances in the amount, type and pattern of vegetation removed and remaining. However, this strategy comes with the cost of unexpected differences between anthropogenic treatments and natural disturbances.
Intermediate Disturbance Hypothesis

Disturbance regimes are postulated to have a dramatic affect on ecological diversity by creating heterogeneity in the physical environment and interfering with biotic interactions. Early ecologists noted that in fact intermediate levels of disturbance create conditions that support the greatest diversity of species. This observation has been formalized into the ‘intermediate disturbance hypothesis’ which has the following postulates:

- Species richness will be greatest in communities experiencing some intermediate level of disturbance. This can be expanded to infer that biodiversity will be greatest in ecosystems experiencing intermediate levels of disturbance.

- This hypothesis applies regardless of whether the disturbances are biological (e.g., predation in predator-prey relationships) or physical (e.g., wave action functioning as a disturbance agent in inter-tidal zone communities).
• This relationship is based on the fact that disturbances alter the availability of resources (physical, chemical, and biological) and are the source of multiple levels of environmental heterogeneity, and thus produce the diverse environments that form the basis for resource partitioning among coexisting species.

• At low and high disturbance levels, environments tend toward homogenization and competitive relationships lead to selection for fewer species that are best adapted to the predominant environment that is produced.

• At intermediate disturbance levels, maximum environmental heterogeneity is maintained, which allows for maximum niche differentiation and maximum opportunities for coexistence of competing species, as well as predators and their prey.

The intermediate disturbance hypothesis has obvious implications for conservation planning. Areas with intermediate levels of disturbances are likely to contain the greatest diversity of species and thus serve as a logical focus for biodiversity conservation. Conservationists have used this concept not only as the basis for prioritizing sites for conservation protection, but also as the basis for managing conservation lands through active management.
Minimum Dynamic Area

Characterizing the disturbance regime is essential in order to identify the minimum dynamic area for an ecosystem or landscape. Establishing a single isolated reserve in an area subject to infrequent, but catastrophic, large-scale disturbances may be an unwise strategy if the intent is to maintain biodiversity associated with late-successional conditions. A disturbance regime implies an area required to stabilize the dynamics of its patch types, sensu Watt's unit pattern. The minimum dynamic area can be characterized as follows:

- The smallest area with a natural disturbance regime which maintains internal recolonization sources and hence minimizes extinctions (Pickett and Thompson 1978).

  - Min Dynamic Area increases with:
    - increasing disturbance magnitude
    - increasing variance in magnitude
    - decreasing disturbance frequency
    - duration of disturbance (recovery time)

This is the "minimum dynamic area" that conservation biologists and ecosystem managers seek (Pickett and Thompson 1978). It is the minimum area that incorporates all the major pattern-forming processes and it has been used by conservation organizations such as The Nature Conservancy to identify minimum conservation areas within their ecoregional planning approach.
8.2. Implications under Climatic Change

As noted previously, "climate change" scenarios typically imply increases in temperature, and either increases or decreases in precipitation. Most scenarios also imply greater variability in weather and more frequent severe weather conditions (e.g., hurricanes). In considering potential response to climate change, it is important to recognize that altered disturbance regimes may have a more significant impact on landscape patterns than changes in resource levels (e.g., water) and environmental conditions (e.g., temperature).