The importance of disturbance agents and how they affect landscape pattern and process is now well recognized in landscape ecological studies. I explore the current state of knowledge regarding the relationship between pattern, process and disturbance agents. Pickett and White (1985, p.7), defined a disturbance as “any relatively discrete event in space and time that disrupts ecosystem, community, or population structure and changes resources, substrate, or the physical environment”. Disturbances occur over a wide variety of spatial and temporal scales and are characterized (Pickett and White, 1985) by their:
- Distribution
- Frequency
- Return interval
- Rotation period
- Intensity
- Severity
- Synergism

The effects of disturbances on landscape pattern and process include:
- Habitat fragmentation (Patch dynamics)
- Habitat Loss/extinction
- Creation of new habitat
- Increase in species diversity
- Increase in patch number
- Decrease patch size and connectivity
- Increase/ decrease patch edge and isolation
- Changing the behavior, productivity, health, fitness, and persistence of species
- Altering how ecosystem functions and services are delivered

The effects that spatial patterns and changes in landscape structure have on the distribution, movement, and persistence of species are the focus for landscape ecological studies (Turner, 1989). By understanding how disturbances vary in space and time, through quantifying landscape patterns and changes, we can predict the effects of disturbances on the population productivity. The interactive effects of disturbances operating at various scales produce the observed landscape mosaic; however they are difficult to predict (Turner, 1989). Previous studies on the effects of disturbances have focused on a single taxonomic groups and the ability to use the results from one study to predict patterns in other areas remains ambiguous (Dunn, 2004). Landscape pattern and process are influenced by both natural and anthropogenic disturbances such as fires, hurricanes, droughts, floods,
insect outbreaks, logging, infrastructure development, mining, and oil and gas exploration activities.

The level of spatial heterogeneity in the landscape either enhances or diminishes the spread of disturbances and therefore influences landscape patterns and processes. Studies quantifying the role of periodic natural disturbances in influencing landscape pattern and processes, have found that they are important agents in promoting species diversity through maintaining spatial heterogeneity (McIntyre and Hobbs, 1999; Brawn et al. 2001). Landscape fragmentation as viewed by humans may be perceived differently by other species (McIntyre and Hobbs, 1999). The scale at which organisms perceive their environment determines how disturbances affect the population productivity of a particular species. The human perspective of the state of the landscape is described as intact, variegated, fragmented and relictual while the organism view of the landscape state is dependent on the mobility of the organism and the landscape state (McIntyre and Hobbs, 1999). The mobility of a particular taxa may influence their ability to disperse to new areas after a disturbance, with less mobile species likely to be impacted the most.

There is a need to strike a balance between infrastructure development and conservation objectives that promote spatial heterogeneity to enhance species survival and fitness (Brawn et al. 2001). Human induced disturbances may result into habitat fragmentation or landscape variegation and both should be viewed as representative segments along a continuum of landscape dynamics (McIntyre and Hobbs, 1999). Impacts of both natural and anthropogenic disturbances such as a stand replacing fire and a clear cut both lead to the removal of trees however their impacts on long term species composition and population productivity are likely to be different (Turner, 1989; Brawn et al. 2001; Dunn 2004). The theory of island biogeography is an important concept in describing landscapes in terms of the patch, corridor, matrix paradigm (McIntyre and Hobbs, 1999). In unaltered landscape endogenous disturbances operate to maintain ecosystem function while in the altered landscape endogenous disturbances may be at play along exogenous disturbances (McIntyre and Hobbs, 1999).

Landscape dynamics from human induced disturbances arise due to competing land use scenarios that affect spatial patterns, as well as the resident wildlife. Disturbances in tropical forests influence the regeneration of different species of plants due to the varying levels of the sun’s energy that are allowed through the gaps created in the canopy (Chapman et. al, 2000; Martins and Engel, 2007). Impact on the regeneration of plants influences the diversity and population viability of the resident wildlife. The soil seed bank is one of the pathways in which a forest recovers from disturbances and seeds from less disturbed forests have higher chances of regeneration. The season (wet or dry) in which the disturbance takes place has an influence on the species of plants that are likely to regenerate (Martins and Engel, 2007). Species specific responses were observed among primates along a temporal disturbance gradient (28years) with some species indicating continuous decline after logging (Chapman et al. 2000). Low intensity selective logging in Kibale National Park (a moist ever green forest), Uganda was found to be compatible with primate conservation compared to high intensity logging (Chapman et al. 2000). Differences in species richness were observed due to tropical forest conversion by logging and agriculture in tropical forests in Africa, Asia and the America’s (Dunn, 2004). Forest conversion to agriculture reduces species richness significantly compared to selective logging (Dunn, 2004). The effects of synergism as a
characteristic of disturbances that influence landscape patterns and processes are not well known.

Ecological integrity of landscapes can be assessed through comparing the landscape pattern and structure between a disturbed and undisturbed landscape that occur on similar landforms (Mladenoff et al. 1993). The comparisons could further provide the means of relating the functional importance of the observed landscape pattern and how it varies with forest management plans and biodiversity conservation (Mladenoff et al. 1993). Two landscapes with different land use history (Disturbed and intact) were evaluated in terms of landform, soils, and vegetation. Patch distribution and landscape diversity, adjacency analysis, and fractal analysis were carried out (Mladenoff et al. 1993). The results indicate that human disturbed landscapes produce complex forest patches, enhance the growth of new dominant species as well as their spatial relationships (Mladenoff et al. 1993). The successional pathways in the disturbed landscape are likely to converge and the spatial differences observed might help in the implementation of forest landscape restoration, design and management.

Field experiments with replicates provide the link between habitat fragmentation and ecological processes (McGarigal and Cushman, 2002). However the methods employed in these field experiments vary and there is need to interpret the results with caution. There are two experimental approaches (measurative and manipulative) that are used to study the effects of habitat fragmentation on landscape integrity (McGarigal and Cushman, 2002). Some of the important questions that are the focus during studies that involve habitat fragmentation include; “What are the relationships among patch area, patch shape, patch isolation, edge, the interaction of these factors and various population and ecosystem processes?” , “How do various landscape elements, such as corridors, linear network, matrix, affect various ecosystem processes and connectivity of populations in fragmented landscapes?” (McGarigal and Cushman, 2002). Choosing a particular approach in the study of the effects of habitat fragmentation on landscape integrity will ultimately depend on the questions being asked.

The rate of forest fragmentation due to clear cutting was found to differ among ownerships in a forest landscape in Oregon (Spies et al. 1994). Forest loss was highest on private lands, intermediate in public non-wildness and least in wildness areas (Spies et al. 1994). The study suggested that the differences in the rate of forest fragmentation were a result of management objectives that focused to maximize profit in a short period. Cutting rate and cutting pattern were found to produce differing impacts on the amount of edge and interior forest (Spies et al. 1994). The extent of the impact of fragmentation on forest connectivity depends on the rate of disturbance and regrowth, however in tropical regions forest clearance is often replaced with agriculture unlike in temperate conifer forests where forest succession is the norm (Spies et al. 1994).

Mechanistic and stochastic approaches are essential in modeling fire disturbances (He and Mladenoff, 1999). The two approaches differ on a temporal scale, however they have common features that help in describing fire behavior (He and Mladenoff, 1999). Forest Landscape dynamics (LANDIS) a spatially explicit stochastic, raster model is designed to simulate forest succession and disturbances and was used to examine how disturbance regimes and species dynamics interact over a large heterogeneous landscape in northern Wisconsin, USA (He and Mladenoff, 1999). The model incorporates cohorts of individual species, fuel regimes, mean fire/wind return interval and time since last fire/wind disturbance (He and Mladenoff, 1999). Some areas have higher probabilities of fire
occurrence in terms of ignition, location, size and shape (He and Mladenoff, 1999). Fire spread as simulated by a LANDIS model; is a function of spatial configuration, wind direction, fire size, fire probability, susceptibility and fire tolerance of species (He and Mladenoff, 1999). The forest landscape simulation model illustrated that fire may have long term alterations to forest landscape patch structure that persists for decades, with some species needing a 100-500 years to establish themselves to former proportions. The LANDIS model further provides an understanding of species responses to varying levels of disturbance regimes and intervals. The next generation forest landscape simulation model (LANDIS II) was designed as an improvement to LANDIS models and includes various time steps for different ecological processes (Scheller et al. 2007). The model behavior was demonstrated through application to an a boreal forest located in northeast of Winnipeg, Manitoba, Canada. The functionalities of the original LANDIS model were maintained, however LANDIS II extends the variable spatial resolution which are complemented by variable time steps that allow simulations of ecological process at temporal resolutions desired by a particular study (Scheller et al. 2007). The LANDIS II model simulations allow complex interactions to be visualized over large temporal and spatial scales.

Conclusion:

There is substantial literature on the effects of disturbances on landscape patterns and processes, however the impacts produced due to the interaction of the different disturbance regimes and agents that operate at various scales is poorly understood. In addition, the ability to apply the different models developed for specific regions to other regions that are nearly identical remains among the biggest challenges in understanding the pattern-process-disturbance relationships due to the various confounding factors and scales involved.

Conservation approaches for some of the disturbance-dependent species is to employ the restoration of the natural disturbance regimes, however this is only possible at large scales. The most interesting papers that I read focused on examining the role and outcome that disturbances have on pattern-process relationships as well as how disturbances may not necessary lead to loss of biodiversity but through promoting spatial heterogeneity the landscape is able to support a diversity of species. The concept of how the human perspective view of landscape pattern and process differs from the organism’s view of the landscape (which differs among the different species as well) emphasizes why some species show no effect from fragmentation whereas others show pronounced effects like population decline. It’s apparent that most landscapes cannot provide all the ecosystem values needed for the survival of a species and the need to consider each, reserve, each patch as a functional unit of a larger landscape should be the goal of landscape ecology.
Annotated Bib;


In this paper Brawn et al. discussed how natural disturbances lead to an increase in the diversity of bird species by affecting habitat structure and composition of a landscape. In addition their review suggests that human induced disturbances are the leading cause of habitat loss however the control of natural disturbances through management has also contributed to habitat loss. Due to habitat loss bird species dependent on disturbance mediated habitats are declining. The review indicated that there is relationship between disturbance regimes and the structure of bird habitats. They proposed management scenarios that involve manipulating both natural and anthropogenic disturbances in order to diversify the habitat of birds at different scales.


This is a well written paper by Chapman et al. and they examined how species that inhabit disturbed landscapes responded to the changes in habitat structure and composition on a temporal scale. They analysed surveys conducted over a 28 year period and found that, there were differences among rates at which the different primates recovered from low and high intensity selective logging. The study demonstrated that for logging to be compatible with primate conservation, primate populations should be able to recover from the disturbance. They propose that low intensity logging should the preferred choice when carrying out conservation planning. However, generalizations to a number of species in other regions should be interpreted with caution.


In this paper Dunn (2004) explores how different disturbances influence species richness of ants, birds and Lepidoptera in tropical landscapes located in Africa, Asia and the America’s. Forest conversion to agriculture was found to reduce species richness of ants, birds and Lepidoptera compared to selective logging. The differences could be due to varying levels in severity of the two disturbance agents on the forest patterns and processes. However the interacting effects of the disturbance variables remains poorly understood and suggestions were made for future research to focus on synergism. Small scale agriculture and logging were both found to be compatible to conservation of species diversity.

This is a well written paper in which the Authors examine the use of landscape simulation models in providing insights about fire disturbance regimes and recovery of forest landscapes. They used forest landscape dynamics (LANDIS) a spatially explicit stochastic model that incorporates various aspects of fire behavior. The model was used over a large heterogeneous landscape in northern Wisconsin, USA with varying fire return intervals. The results illustrated complex dynamics across a temporal gradient that produce feedback mechanisms. In addition, understanding the patterns produced the associations between the different species and the recovery period, provides new insights into simulation modeling.


McIntyre and Hobbs discussed how habitat fragmentation varies at different spatial scales. They proposed that habitat configurations should be considered on continuum scale instead of a simple classification of habitat versus non habitat. The study suggested that, there exists a difference between how humans perceived the landscape patches as compared to other biota. The patch, corridor, matrix paradigm represents a human perspective of the landscape and therefore the landscapes should classified according to how species respond to it. They concluded that Management of altered landscapes should focus on maintaining the least modified landscapes as effective habitat restoration is extremely difficult.


In this paper Martins and Engel explore soil seed banks in tropical forest fragments which represent one of the pathways that help in the regeneration of plants after a disturbance. They studied soil seed banks in two semi deciduous seasonal forest fragments that varied in disturbance histories. Their results suggested that, the types of species that regenerate are dependent on the severity of the disturbance as well as the time of the year. They concluded that seed banks may not be the primary source of natural regeneration in semi deciduous forests as compared to other types of ecosystems.


In this paper Mladenoff et al. examine the spatial differences created by anthropogenic disturbances. Two landscapes with the same landform, soils, and vegetation but different land use history were compared to explore how human disturbances affect spatial pattern. Differences in terms of patch size, shape, complexity and species composition were evident
in the two landscapes. The structural differences exhibited in the two landscapes need to be tested in other regions so that they can form the basis of implementation of forest landscape restoration, design and management programs.


This is a well written review that discusses the strength and weakness of the experimental approaches that are used to study the effects of habitat fragmentation on landscape integrity. A total of 134 papers on habitat fragmentation were reviewed. Manipulative and measurative approaches were examined. Manipulative experiments allow the experimenter to control the variables and make inferences with reference to a specific variable. Measurative experiments involve observing the system at different locations or time. However manipulative experiments are difficult to implement because of the spatial and temporal scales, limited resources and the heterogeneity of landscapes. Measurative experiments provide an option devoid of limitations on temporal and spatial scales. The review suggests that more experimental studies are required at landscape level.


In this book chapter Pickett, S.T.A., and P.S. White, discuss the dynamics of landscape patterns and processes as they are influenced by natural disturbances. They explain how natural disturbances play a fundamental role in landscape dynamics at different temporal and spatial scales. They emphasize patch dynamics, perturbations and disturbances as central concepts that represent the general theme of landscape dynamics. Causes of disturbances were classified into endogenous and exogenous categories however they also noted that distinctions were difficult to make in natural systems. This is a well written book chapter and is a great introduction to understanding the role of natural disturbances in creating spatial heterogeneity.


In this paper Scheller et al. discuss the use of the next generation forest landscape simulation model (LANDIS II) which is an improvement from LANDIS that was designed to model forest succession and disturbance regimes. However LANDIS II additional functionalities include the use of time steps in simulating the different ecological processes. The model behaviour was applied to a large boreal forest landscape on pre-industrial fire regimes in order to guide future forest management decisions. The LANDIS II models provide the user with the flexibility to select various variables that affect forest succession and disturbance.

In his paper Spies et al. discuss the process of forest fragmentation by comparing the rates and pattern of clear cutting and regrowth. They found that there was a relationship in the rate of forest cutting and the type of ownership (Private, Public, Wilderness). The landscape dynamics of the relations of edge and interior forest habitat to percentage cutover in the different ownership areas supported the simple checkerboard model of Franklin and Foreman (1987). However the model could not clearly account for the complexities of landscape pattern and dynamics. The landscape patterns of the interior forest that were observed provide a baseline in developing and implementing future landscape patterns for interior sensitive species.


In this paper Turner (1989) discusses how the effects of spatial patterns affect ecological processes. The review emphasizes how pattern and process differentiates landscape ecology from other ecological disciplines. The focus on how spatial and temporal scale affects the interpretation of the results obtained from studying the structure, function, and change of landscapes was an interesting read. The review suggests that the observed landscape spatial patterns are due to natural and human induced disturbances which are characterized through measuring landscape metrics. Through understanding how disturbances vary in space and time at different scales we can accomplish the primary goal of explaining the relationship between landscape patterns and ecological processes. In addition the review, suggested that the future of landscape ecology should be oriented towards implementation and hypothesis testing in actual landscapes.