Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.6, No.15, 2016

A Review on the Effect of Habitat Fragmentation on Ecosystem

Dagnachew Mullu
Department of Biology, College of Natural Sciences, Arba Minch, University
PO Box 21, Arba Minch Ethiopia

Abstract
Habitat fragmentation is considered a primary issue in conservation biology. This concern centers around the disruption of once large continuous blocks of habitat into less continuous habitat, primarily by human disturbances such as land clearing and conversion of vegetation from one type to another. Habitat loss and fragmentation are the primary causes of species extinction worldwide. The largest single threat to biological diversity worldwide is the outright destruction of habitat, along with habitat alteration and fragmentation of large habitats into smaller patches. Fragmentation is caused by both natural forces and human activities, each acting over various time frames and spatial scales. Physical Features of the landscape, associated with very slow geomorphic processes (e.g., erosion) may also cause some patches to remain isolated over evolutionary time-scales. The effects of fragmentation also vary depending on the cause of fragmentation (for example, fragmentation of agriculture versus for logging). As a result, there is necessity to take effective actions to maintain biodiversity in fragmented landscapes.
Keywords: corridors, fragmentation, island, habitat, metapopulation.

1. Introduction

Landscapes all over the world are being fragmented at an unprecedented rate due to fragmentation of the natural habitats of wildlife. These influenced the process of species extinction in several populations. Whether it is wise to connect habitat remnants together with dispersal corridors or leave such isolated populations to evolve and fluctuate on their own and whether it is better to protect a single large area or a set of smaller isolated areas in biological reserves, are questions that require immediate attention before the possibility of taking actions to reduce the effect of habitat fragmentation (Reed, 2003). Habitat loss and fragmentation are the primary causes of species extinction worldwide (Weidong *et al*., 2002).

Habitat fragmentation is considered a primary issue in conservation biology (Meffe and Carroll, 1997). This concern centers around the disruption of once large continuous blocks of habitat into less continuous habitat, primarily by human disturbances such as land clearing and conversion of vegetation from one type to another. The classic view of habitat fragmentation is the breaking up of a large intact area of a single vegetation type into smaller units (Lord and Norton, 1990).

Habitat fragmentation involves the splitting of natural habitats and ecosystems into smaller and more isolated patches. It reduces the availability and the suitability of adjacent areas for wildlife. This process leads to conditions whereby individual animal and plant species, as well as their wider populations, to become endangered leading to extinction. Fragmentation is a complex process, in which the loss and isolation of natural habitats are the most important factors. It is a process in which one continuous habitat is transformed into a larger number of smaller patches, of smaller total area, isolated from each other by a matrix, which is usually compositional or structurally different from the original habitat (Wilcove *et al*., 1986). This process implies habitat loss, but also a change in habitat configuration (Fahrig, 2003), that implies different number of fragments or relative isolation among them. Classical theories in community and population ecology, such as the Theory of Island Biogeography (MacArthur and Wilson, 1967) and the Theory of Metapopulation Dynamics, predict that smaller and more isolated fragments support an impoverished fauna, compared to larger and closer fragments. Many empirical data have supported these predictions, suggesting that habitat fragmentation negatively affects the abundance and species richness of organisms (Levins, 1969). But, as most researchers have not separated the effects of habitat loss and habitat configuration, the negative effects attributed to habitat fragmentation may be representing only the negative effects of habitat loss (McGarigal and Cushman, 2002). Fahrig (2003) pointed out that while habitat loss has large, consistent negative effects on biodiversity, a change in habitat configuration has a much weaker effect, and may be negative but also often positive. The positive effects recorded involves (Collins and Barret, 1997), crabs (Caley *et al*., 2001) and insects (Collinge and Forman, 1998). On the one hand, habitat fragmentation may increase population density through a crowding effect, where surviving individuals move from the removed habitat to the remaining fragments (Collinge and Forman, 1998). Nevertheless, this may be a short-term effect (Debinski and Holt, 2000). On the other hand, habitat fragmentation may increase species richness, both in the fragment (i.e., local, species diversity) as well as in the landscape (i.e., regional, species diversity) level, not only because of the crowding effect, but also due to a series of small or medium-sized fragments distributed in a larger area and relatively far apart from each other (Collinge and Forman, 1998).

By far, the largest single threat to biological diversity worldwide is the outright destruction of habitat, along with habitat alteration and fragmentation of large habitats into smaller patches (Meffe and Carroll, 1997). The two components of habitat fragmentation are: 1) the reduction of the total amount of a habitat type in a landscape; and 2) the reapportionment of the remaining habitat into smaller, more isolated patches of habitat. The magnitude of habitat fragmentation reflects the influence of humans on the environment from local through regional, national and global. While the direct effects of habitat loss are typically considered to pose the greatest current threat to biodiversity, the size and spatial arrangement of remnant fragments is recognized to have a major effect on population dynamics and species persistence (Lord and Norton, 1990) , with impacts that are more dangerous than habitat loss alone (With, 1997). As a consequence, habitat fragmentation has become a central issue in conservation biology (Meffe and Carroll, 1997).

1.1. Definition

Habitat fragmentation can be described as the splitting of natural habitats and ecosystems into smaller, more isolated patches (Fig. 1, C). It is the process of subdividing a continuous habitat into smaller pieces (Fig. 1, A). It implies a loss of habitat, reduced patch size and an increasing distance between patches, but also an increase of new habitat It is defined as the breaking apart of the connectivity of habitat (Fig. 1, B) (Andren, 1996). The term fragmentation has been used to encompass a broad variety of changes in landscapes, changes that include reduction in habitat area, increased isolation of habitat patches, extension of the length of edges between habitats, and amplified contrast between habitat and the surrounding matrix (Fahrig, 2003).

Fragmentation is the dissection of landscapes into spatially isolated parts, is a major driver of environmental change worldwide (Fischer and Lindenmayer, 2007). Usually, the process of fragmentation is caused by human activities (roads, agriculture and logging). It also reduces the value of the landscape as habitat for many species. It alters natural habitat in many ways, including reduction of patche sizes, increase of distances between similar patches and increase of edges (Robinson *et al*., 1995). Landscape fragmentation customarily refers to a reduction in connectivity between parts of a landscape or the conversion of the landscape into a mosaic of cover types, some of which differ from the original habitat. Ecological implications of these changes remain unknown (Southworth *et al*., 2004).

Habitat fragmentation is often defined as a process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original (Wilcove *et al*., 1986). By this definition, a landscape can be qualitatively categorized as either continuous (containing continuous habitat) or fragmented, where the fragmented landscape represents the endpoint of the process of fragmentation. This definition of habitat fragmentation implies three effects: (*a*) reduction in the extent of habitat, (*b*) increase in number of habitat patches, and (*c*) increase in isolation of patches. These effects form the basis of most quantitative measures of habitat fragmentation. However, fragmentation measures vary widely; some include only one effect (e.g., reduced habitat or reduced patch size), whereas others include more.

1.2. Theory of habitat fragmentation

The two key theoretical developments in community and population ecology to study fragmentation are: the Theory of Island Biogeography (MacArthur and Wilson, 1967) and the Theory of Metapopulation Dynamics (Levins, 1969).

1.2.1. Theory of Island Biogeography

In the context of habitat fragmentation, the Theory of Island Biogeography has focused primarily on the influences on habitat fragment size and isolation of species composition (Robinson *et al*., 1992).

The theory of island biogeography (MacArthur and Wilson, 1967), which accounts for the observation that the number of species on islands is lower than in the mainland areas of comparable size. It proposes that species richness on islands represents a balance between the rate of colonization of new species and of extinction of species already present (Fig. 3). The rate of colonization is determined primarily by isolation from the mainland, the rate of extinction mainly by island size. A small island will have fewer species than a larger island of comparable isolation and for islands of similar size, those that are distant will have fewer species than those close to a mainland source (Fig. 2). This theory extends to mainland isolates and habitat fragments and a framework for studying the effects of habitat fragmentation (Diamond, 1975). The theory that species richness and individual abundance will decrease with reduced patch size (Fahrig, 2003). The concept of isolation has also changes somewhat from distance to a mainland to distance between neighboring patches (Haila, 2002).

It proposes to explain species composition of animal communities on oceanic islands. In particular, this theory postulates that the size of an oceanic island and its distance from a continental source of colonizing species will determine the number of species present on the island. Islands close to a mainland will have higher immigration rates than more distant islands, and large islands will have lower extinction rates than small islands. Thus, large islands close to continents are predicted to have a higher number of species than small islands which are more distant from continents. Species on island represent a dynamic equilibrium between the immigration of new colonizing species and the extinction of previously established ones. This theory focuses on species composition on oceanic islands, the predictions may be consistent for plant and animal communities inhabiting terrestrial islands (MacArthur and Wilson, 1967).

1.2.2. Theory of Metapopulation Dynamics

The Theory of Metapopulation Dynamics concept has focused attention on connectivity and interchange between spatially distributed populations (Hanski *et al.*, 1995). Metapopulation theory was originally conceived to describe and predict the population dynamics of species occupying naturally patchy habitats (Levins, 1969). A metapopulation is a set of spatially separated groups of conspecific individuals. In this model, local populations of organisms undergo periodic colonization and extinction, while the metapopulation as a whole persists indefinitely (Fig. 4). Ecologists have directly applied the understanding of the oscillations of such naturally transient populations to predicting the persistence of species which occur in human-induced habitat fragments (Hanski *et al.*, 1995).

Like Island Biogeography Theory, this theory also focuses on local extinctions and colonization in the context of heterogeneous spatial pattern of habitat patches. It differs from island biogeography by the following points. It assumes a network of small patches with no mainland habitat and it considers population dynamics of only one species at a time (Hanski, 2002).

1.2.2.1. Landscape Dynamics

The higher the rate of landscape change, the lower the probability of regional population survival. The rate of change in landscape structure may be more important than the degree of patch isolation for determining population survival and abundance. This body of spatial theory suggests that habitat configuration is important, above and beyond the effects of a loss in habitat area associated with fragmentation processes. Thus, spatial management strategies for increasing landscape connectivity, and increasing area/edge ratios, should help to alleviate habitat fragmentation effects (Kindvall, 1996).

2. Spatial and ecological attributes of habitat fragments

Numerous ecological studies have investigated the consequences of habitat fragmentation for plant and animal population persistence, community composition, and ecosystem processes. For example, many studies relate the number of animal or plant species observed in fragments to some designated fragment characteristics, usually area, shape, degree of isolation, context, or some measure of habitat quality or heterogeneity. While each of these attributes plays an individual role in determining ecological function, they may also interact to influence ecological processes. Each of these fragments characteristics separately, recognizing that there are correlations among them (Fahrig, 2003).

2.1. The edge phenomenon

Edges are often sites of intense interactions that strongly influence the biotic units so bounded (Wallace *et al.*, 1997). The term edge effect is a collection of different phenomena (Lidicker and Peterson, 1999). It is the portions of a fragment that are altered by external conditions, while unaffected portions are called core habitat. The proportion of a fragment that is core habitat is a complex function of fragment size and shape and the nature of the surrounding landscape matrix (Laurance and Yensen, 1991).

Conversion of continuous habitat into disjunct habitat remnants usually increases the length of the border between fragments and their surrounding habitats. Particularly in forests, because of their dominant vertical structure, removal of vegetation from an area results in dramatic changes in the structural characteristics of the habitat (Murcia, 1995). Isolated forest remnants, which were once embedded in continuous forest, are exposed to the altered physical environment of the adjacent cleared area. The amount of light reaching plants is obviously higher at the edge of a forest fragment than in the forest interior. Consequently, temperature increases and relative humidity decreases at the forest edge. Moreover, wind velocities are higher at the edge than in the interior of the forest. The changes in light, moisture, temperature, and wind, most pronounced at the fragment edge, may significantly alter the plant and animal communities which occur there. Additionally, the extent to which the edge experiences these environmental changes may be significantly influenced by the aspect or orientation of the edge. In the Northern Hemisphere, south-facing edges are generally warmer, drier and wider than north-facing edges; the opposite is true in the southern hemisphere. Similarly, windward edges of forest patches tend to be warmer, drier and wider than leeward edges (Harris, 1984).

Associated with the changes in light, temperature, moisture and wind conditions at forest edges are changes in the structure and composition of the existing plant communities. For example, in the deciduous forest patches of southeastern Wisconsin, forest edges typically contained more pioneer and xeric plant species than the interior, higher densities of shrubs and herbaceous ground layer vegetation for several meters into the forest, and higher species richness than the interior. Higher species richness in forest edges may often be due to the invasion of exotic plant species (Ranney *et al.*, 1981).

Some animals appear to select or prefer edges as suitable breeding habitat, despite the fact that mortality rates at edges can be much higher than in fragment interiors. This phenomenon has been termed as ecological trap (Ries and Fagan, 2003). Edges support higher β-diversity than fragment interiors (Didham *et al.,* 1998). It also increases variability in trophic interaction strengths which results hyper-dynamism in a range of ecosystem process rates, where the frequency and/or amplitude of ecosystem dynamics is increased. Hyper-dynamism can result in the destabilization of animal populations (Laurance, 2002).

2.2. Fragment size/area

The size of a particular habitat fragment markedly influences the ecological processes occurring therein, partly due to the changes induced by the creation of habitat edges discussed above. Because edge effects in a particular habitat there is a constant distance from the border to the center of a habitat fragment, smaller fragments will contain a higher proportion of edge habitat than will larger fragments. The decline in species richness in small habitat remnants results from decrease in population size of a particular species, and eventually, local extinction of those populations. Population decline due to direct effects of habitat loss, or due to indirect effects, for example, modified interspecific interactions associated with habitat isolation and edge effects. As fragment size increases, the relative proportion of edge habitat decreases, and interior habitat increases (Groom and Schumaker, 1993).

2.3. Fragment connectivity

Landscape connections play an important role in ecological dynamics within and between habitats. The conservation of vegetated corridors among otherwise isolated habitat remnants is predicted to moderate the negative effects of habitat fragmentation by maintaining landscape connectivity. In the context of ecological studies of habitat fragmentation, the term corridor generally refers to a linear landscape element composed of native vegetation which links patches of similar, native vegetation. The integrity of riparian corridors, in particular, is of critical importance in preventing soil erosion and maintaining high water quality. It is well documented that vegetation in riparian zones provides bank stability and control of water flow regulates light and temperature characteristics of the adjacent water bodies, and provides habitat for aquatic life in the form of coarse and fine woody debris (Naiman *et al*., 1993).

Vegetated corridors are predicted to facilitate the movement of plants and animals among habitat fragments, which may allow more species to exist and/or populations to persist longer than would be expected based solely on fragment size. For example, computer simulations have suggested that populations of the white-footed mouse, *Peromyscus leucopus,* have higher growth rates and thus lower probabilities of local extinction in woodlots connected by fencerows than in isolated woodlots (Fahrig *et al.*, 1983). A recent experimental field study in an agricultural landscape showed that vole dispersal was greater between old-field fragments connected by vegetated corridors than in completely isolated fragments (Harris and Scheck, 1991).

Animal use of corridors may vary depending upon their foraging patterns, body size, home range size, degree of dietary specialization, mobility and social behavior. Lindenmayer and Nix (1993) noted that linear remnants of Montana forest harbored several species of large, arboreal marsupials, while smaller species were absent. These authors suggested that species occurrence in these corridors was largely determined by foraging behavior and social behavior rather than body size. Large animals foraged singly and fed on readily available leaves, while smaller species foraged in social groups and fed on more widely dispersed arthropods. The perception and use of corridors by animals may also differ according to the physical dimensions and landscape context of the corridor. For interior habitat specialists, the typically long, narrow dimensions of a corridor may be perceived as largely edge habitat and avoided. Because it does not facilitate movements of larger sized animals through it. And the animals which can pass through it will be exposed to danger due to its longer size.

Moreover, how such movements via vegetated corridors might translate into population persistence and community composition of native habitats is not well understood. The existence of vegetated corridors between otherwise isolated habitat fragments may modify patterns of species richness and composition by increasing the effective size of the fragments. Thus, connected remnants would be predicted to maintain the attributes of continuous habitat, and support a greater biological diversity than completely isolated remnants (Groom and Schumaker, 1993).

2.4. Fragment shape

The geometric shape of a discrete habitat fragment influences the extent to which edge effects permeate (spread through) the habitat interior. Size and shape thus interact to influence the amount of interior area remaining in a particular habitat fragment. Shape can be described most simply by calculation of the perimeter/area ratio of a habitat fragment. A square habitat fragment maintains a greater proportion of interior habitat than does a rectangular fragment of equal area (Groom and Schumaker, 1993).

2.5. Fragment context

The context in which a remnant of native habitat is situated will undoubtedly influence the degree and type of interaction between the fragment and the surrounding landscape. The assertion of Janzen (1983) that no park is an island emphasized the influence of surrounding habitat types and human activities on the ecological integrity of areas reserved for conservation.

The type, intensity, and degree of dissimilarity of habitat types, land uses and human activities adjacent to habitat fragments may markedly influence the flow of nutrients and materials, and the persistence of plant and animal species in the fragments. The relative importance of these adjacent land-uses on ecological processes will depend upon other spatial characteristics such as fragment size and shape (Janzen, 1983).

The boundary between a habitat fragment and its surrounding matrix may be relatively impervious, with a low tendency for the exchange of materials and organisms between the remnant and the matrix. Alternatively, the boundary may be highly porous, in which case there are frequent and abundant boundary crossings. Boundary permeability and the perimeter/area ratio may both influence the rate and extent of flows across the boundary. The supply and flow of nutrients, materials, and energy within habitat fragments, as well as between fragments and the surrounding landscape, will likely differ depending on the adjacent land-use or activity (Wiens *et al.,* 1985).

2.6. Fragment heterogeneity

A factor shown to be partially responsible for the relationships found between species composition and fragment spatial characteristics is the degree of habitat heterogeneity within isolated fragments. Large fragments are more likely to contain a greater variety of soil types, greater topographic variation, greater microclimatic variation, and a greater number of habitat types than small fragments (Boecklen, 1986).

Fragments of approximately equal size, which are relatively heterogeneous tend to support a greater number and variety of species than those which are more homogeneous (Maehr and Cox, 1995). Populations of plants or animals in heterogeneous habitat fragments may be less susceptible to local extinction than those in more homogeneous habitats. For example, populations of bush crickets in Sweden were more likely to persist if they occurred in an area which contained several vegetation types than in an area which contained only a single or small number of vegetation types (Kindvall, 1996). This result was largely due to the existence of greater microclimatic variation in the more heterogeneous habitats, which allowed some individuals to persist even under severe weather conditions. In contrast, areas with little vegetational diversity exhibited little microclimatic variation; thus in severe weather, the cricket populations went extinct. This result suggests that maintenance or restoration of a high diversity of vegetation types within habitat remnants may be essential for long term population persistence. An analysis of temperate zone, forest birds demonstrated that the structural diversity of forest vegetation significantly influenced bird species composition, in addition to forest fragment size (Kindvall, 1996).

3. Causes of habitat fragmentation

Fragmentation is caused by both natural forces and human activities, each acting over various time frames and spatial scales. Physical Features of the landscape, associated with very slow geomorphic processes (e.g., erosion) may also cause some patches to remain isolated over evolutionary time-scales (Schule, 1990).

3.1. Fragmentation Due to Natural Causes

1. Over long time frames (thousands or millions of years), landscapes are fragmented by geological forces (e.g., continental drift) and climate change (e.g., glaciations, changes in rainfall, sea level rise).
2. Over short periods (decades or months), natural disturbances, such as forest fires, volcanoes, floods, landslides, windstorms, tornadoes, hurricanes and earthquake modify and fragment landscapes.

In addition, landscapes are naturally fragmented by mountain ridges, canyons, rivers and lakes. Some ecosystems also commonly occur in discrete patches and are thus naturally fragmented. Natural processes create the habitat heterogeneity and landscape diversity upon which many species depend.

3.2. Fragmentation due to Human Activity

The most important and largest-scale cause of changes in the degree of fragmentation is anthropogenic habitat modification, with nearly all fragmentation indices being strongly correlated with the proportion of habitat loss in the landscape (Fahrig, 2003).

Humans have modified landscapes for thousands of years. Early hunters influenced the landscape by burning areas to favor certain game species, as currently ranchers burn grasslands. Many human activities such as agriculture, settlement, resource extraction (e.g., mining, timber), industrial development (e.g. the construction of hydroelectric dams) alter and fragment landscapes. Of these activities, agriculture is the leading cause of ecosystem loss and fragmentation throughout the world today (Tilman *et al*., 2001).

3.3. Natural *Vs.* Human Fragmentation

Several differences exist between human-caused and naturally fragmented landscapes (Fahrig, 2003):

1. A naturally patchy landscape often has a complex structure with many different types of patches. A human-fragmented landscape tends to have a simplified patch structure with more distinct edges, often with a few small patches of natural habitats in a large area of developed land.
2. Patch types in human-modified landscapes are often unsuitable to many species, while in a heterogeneous natural landscape most patch types are suitable to a more diverse group of species.
3. The borders (or edges) of patches in naturally patchy landscapes tend to be less abrupt than in those created by humans.

4. Adverse effects of habitat fragmentation

Habitat fragmentation results in both a quantititative and qualitative loss of habitat for species originally dependent on that habitat type (Temple, 1986). As a consequence, the abundance and diversity of species originally present often declines, and losses are most noticeable in smallest fragments. Most importantly, fragmentation affects movement and dispersal and modifying behavior (Haila, 2002). The process of habitat fragmentation involves three factors, which have important repercussions on plant and animal species that originally occupied large continuous areas of wild habitat (Schimiegelow and Monkkonen, 2002).

First, fragmentation leads to the breaking of large patches into numerous smaller, resulting in a net habitat loss. This results in a decrease in the amount of resources and shelter areas available to wild species and, therefore, leads to a general reduction in the number of individuals that can be hosted. The most obvious effect of fragmentation is an outright quantitative loss of habitat for species dependent on the original habitat type in a region groups of species directly impacted by habitat loss through fragmentation including those with large home range requirements, very specific microhabitat requirements, and poor disposal abilities.

Second, by opening core areas, fragmentation of continuous habitat patches, leads to a dramatic increase in edges. Edges present distinct micro-climatic conditions from the core and therefore might become less suitable for species. These edges also lead to higher predation rates by favoring generalist predator influx, which in turn greatly impacts the population of resident species.

Third, habitat fragmentation results in the geographic isolation of islands of habitat among a matrix of urban or agricultural land-uses. This might greatly restrict the mobility of certain organisms, and thereby isolate some populations. However, small isolated populations can be threatened by inbreeding, which represents a serious problem for their survival and could lead, in case of severe inbreeding to population extinction. Moreover, small populations are more sensitive to stochastic events, such as fires or epidemic outbreaks that could drive local population to extinction.

The isolation of habitat patches increases and the probability to be recolonized decreases. Therefore, long-term survival of isolated populations cannot be assumed in any case. Nonetheless, not all species have the same sensitivity to habitat fragmentation. Naturally rare, sedentary species, with specialized in habitat requirement show an important decline whereas abundant mobile generalist species are less affected or even favored, in the case of edge specialists. Also the degree of isolation of habitat patches might depend on the migration capacity of each species living within them. As a consequence, habitat fragmentation cannot be generally described, and should be specified for every individual species (Parker and Nally, 2002).

Habitat fragmentation creates landscapes made of altered habitats or developed areas fundamentally different from those shaped by natural disturbances that species have adapted to over evolutionary time (Meffe and Carroll, 1997). Generally, according to (Parker and Nally, 2002), adverse effects of habitat fragmentation to both wildlife populations and species include:

• Increased isolation of populations or species, which leads to:
- Adverse genetic effects; i.e. inbreeding depression (depressed fertility and fecundity, increased natal mortality) and decreased genetic diversity from genetic drift and bottlenecks;
- Increased potential for extirpation of localized populations or extinction of narrowly distributed species from catastrophic events such as hurricanes, wildfires or disease outbreaks;

• Changes habitat plant composition, often to weedy and invasive species;
• Changes the type and quality of the food base;
• Changes microclimates by altering temperature and moisture regimes,
• Changes flows of energy and nutrients;
• Changes availability of cover and increases edge effect, bringing together species that might otherwise are not interact, potentially increasing rates of predation, competition and nest parasitism;
• Increases opportunities for exploitation by humans, such as poaching or illegal collection for the pet trade;

Habitat fragmentation diminishes the landscapes capacity to sustain healthy populations or metapopulations in five primary ways: loss of original habitat, reduced habitat patch size, increased edge, increased isolation of patches and modification of natural disturbance regimes (Forman, 1999).

4.1. FRAGMENTATION AS HABITAT LOSS

The most obvious effect of the process of fragmentation is the removal of habitat. This has led many researchers to measure the degree of habitat fragmentation as simply the amount of habitat remaining on the landscape (Robinson *et al*., 1995). When ecologists think of fragmentation, the word invokes more than habitat removal: fragmentation; not only causes loss of the amount of habitat, but by creating small, isolated patches it also changes the properties of the remaining habitat (van den Berg *et al*., 2001).

Habitats can be removed from a landscape in many different ways, resulting in many different spatial patterns. The assertion that habitat fragmentation means something more than habitat loss depends on the existence of effects of fragmentation on biodiversity that can be attributed to changes in the pattern of habitat that are independent of habitat loss. In addition to loss of habitat, the process of habitat fragmentation results in three other effects: increase in number of patches, decrease in patch sizes, and increase isolation of patches. Measures of fragmentation that go beyond simply habitat amount are generally derived from these or other strongly related measures (e.g., amount of edge). There are at least 40 such measures of fragmentation (McGarigal *et al*., 2002), many of which typically have strong relationships with the amount of habitat as well as with each other (Robinson *et al*., 1995).

The interrelationships among measures of fragmentation are not widely recognized. Most researchers do not separate the effects of habitat loss from the configurationally effects of fragmentation. This leads to ambiguous conclusions regarding the effects of habitat configuration on biodiversity. It is also common for fragmentation studies to report individual effects of fragmentation measures without reporting the relationships among them, which again makes the results difficult to interpret (Robinson *et al*., 1995).

4.2. REDUCED HABITAT PATCH SIZE

Reduction in habitat patch size is a principal consequence of fragmentation. MacArthur and Wilson have suggested that the rate of species extinction in an isolated patch of habitat is inversely related to its size. As habitats become smaller, they are less likely to provide food, cover and other resources necessary to support the native communities. Small patches are also more susceptible to catastrophic disturbance events such as fire or severe weather that can decimate local populations. Fragmentation also decreases the area of interior habitat. Interior habitat is the area far enough from the edge to maintain communities of the original larger habitat (Parker and Nally, 2002).

Once a landscape has been fragmented, the size of the remaining patches is a critical factor in determining the number and type of species that can survive within them. For all species that cannot cross a forest edge or leave a patch, all requirements to complete their life cycle must be met within the patch itself. This is especially important for species with complex life cycles, each with distinct habitat requirements. For example, many amphibian species have aquatic larval stages and a terrestrial adult phase. Also, some species require large areas of continuous habitat and cannot survive in small patches. These are referred to as area-sensitive species. Furthermore, large patches typically support larger populations of a given species and thereby buffer them against extinction, inbreeding depression, and genetic drift (Schimiegelow and Monkkonen, 2002).

4.3. INCREASED ISOLATION

Fragmentation leads to increased isolation of patches. Wildlife populations in isolated patches can be sustained by immigration of species from surrounding patches. However, as fragmentation continues, distances between patches get longer and dispersal and immigration rates decrease. The diversity of species moving between patches also decreases; small species with limited mobility are particularly sensitive. As immigration rates decrease, factors like inbreeding and catastrophic disturbances can cause the number of species in a patch to decline to zero over a long period of time (Robinson *et al*., 1995).

4.4. INCREASED EDGE

Although an increase in edge (the boundary between two plant communities) due to fragmentation may benefit some species, some researchers believe that increasing edge may be detrimental to the protection of native biodiversity. Edges act as barriers causing some predators to travel along them. High predator densities along edges can result in higher mortality for edge dwelling prey species or species moving through narrow corridors. Nest parasitism by brown headed cowbirds (*Molothrus ater*) also appears to be higher in species nesting in edge habitat. Least bells vireo (*Vireo bellii pusillus*) is an endangered species that inhabits the edges of riparian corridors in southern California. Parasitism by cowbirds appears to be as significant as the loss of riparian habitat in the decline of the least bell's vireo on Camp Pendleton, California (Schule, 1990).

One of the most obvious changes to a fragmented landscape is the increase in edge environment. Edge environments or ecotones mark the transition between neighboring habitats. In a naturally forested landscape, edge is usually limited to a small area, (Laurance and Bierregaard, 1997). Natural edges are usually less abrupt than human-formed edges and show a gradual transition from one habitat type to another. Along agricultural frontiers, the original landscape may be fragmented into long narrow strips or shreds, interspersed with areas of agriculture. These strips may separate different crops, thus serving as windbreaks, or the boundary between two landowners. As a result, this remaining fragment is entirely made up of edge environment. Residual trees along rivers provide another example of narrow, edge-dominated environments (Debinski and Holt, 2000).

The extent of edge environment in a fragment patch is determined in part by its shape. The ratio of the perimeter to area (or the amount of edge environment to the amount of interior) is one measure of patch shape. A circular patch has the maximum area per unit edge and will have less edge environment and fewer edge effects than a rectangular patch of the same size. Because edge effects may extend 200 meters (and sometimes more), small patches may be entirely composed of edge environment (Laurance and Bierregaard, 1997).

Edge effect is a general term used to describe a number of different impacts, and can be categorized into several types: physical (e.g., microclimatic changes), direct biological impacts (changes in species composition, abundance, and distribution), and indirect biological impacts (changes in species interactions such as predation, competition, pollination, and seed dispersal). Moreover, many of the effects of fragmentation are synergistic; for example, fragmentation can lead to increased fire risk, increased vulnerability to invasive species, or increased hunting pressure (Hobbs, 2001).

4.5. Effects of Different Types of Fragmentation

The effects of fragmentation also vary depending on the cause of fragmentation (for example, fragmentation of agriculture versus for logging). It is difficult to make generalizations about the effects of a specific type of fragmentation on a particular landscape, as the consequences may be very different in a temperate *vs* tropical region or in a grassland *vs* a forest, largely because the plants and animals present have different sensitivities to fragmentation (Harris and Scheck, 1991).

The potential effects of a particular type of fragmentation based on how the new environment is perceived by the original species present and whether the change to the landscape is permanent or temporary. The matrix that surrounds fragments has a large effect on what species remain it and their dispersal ability between fragments (Hansski *et al*., 1995).

4.5.1. Effects on Species Abundance, Richness, and Density

Impacts of fragmentation on species abundance, richness, and density are complex. Studies of the effects of fragmentation on species abundance, richness and or density relative to fragment size have inconsistent results, some indicating an increase in species and in others, a decline. However, it is important to keep in mind that simply counting the number of species does not measure impacts of fragmentation on behavior, dispersal ability, or genetic diversity (Debinski and Holt, 2000).

Some species respond positively to fragmentation. Fragmentation may increase species richness by allowing generalist species to invade. In a study of the impact of fragmentation on frogs in a lowland Amazonian forest, species richness was strongly and positively related to fragment area. After fragmentation, species richness increased largely as a result of invasion by frog species from the surrounding matrix into the remaining forest fragments. It is unclear if this increase will be sustained over time. For example, if this same spot was re-surveyed in 50 years, total species richness might decline as interior forest species disappear (Laurance and Bierregaard, 1997).

Immediately following fragmentation, the density of individuals may increase as animals crowd into the remaining forest. This inflation of density will ultimately prove short-lived because patches are rarely adequate to support the same population density for long as more extensive habitats (Schmiegelow *et al*, 1997).

4.5.2. Interactions Among Species and Ecological Processes

Fragmentation causes the loss of animal populations by a process termed faunal relaxation, the selective disappearance of species and replacement by more common species. Large-bodied vertebrates, especially those at high trophic levels, are particularly susceptible to habitat loss and fragmentation, and are among the first species to disappear. Thus, predators are often lost before their prey, and those species that do survive on small fragments (usually herbivores) tend to become far more abundant than populations of the same species on larger species-rich fragments. There are two principal explanations for this increased abundance. The first is ecological release from competition: when competing species are removed, the resources they utilized become available to the persisting species. The second is that prey escape to small fragments from predators that normally limit their abundance on larger fragments. Lack of predators in small fragments can also lead to an overabundance of herbivores that tend to weed out palatable plant species and convert the landscape into a forest of herbivore-proof plants. Furthermore, as large predators disappear, smaller predators often increase; this is known as mesopredator release (Soulé *et al*., 1988). For example, in California, as coyotes disappear from fragments, there is an overabundance of smaller predators, such as skunks, raccoons, grey fox, and cats. These smaller predators then prey on scrub-breeding birds. Fragmentation thus triggers distortions in ecological interactions that drive a process of species loss, the end point of which is a simplified ecological system lacking much of the initial diversity (Chalfoun *et al*., 2002).

While predator-prey relationships are often altered in fragmented landscapes, it is not always possible to predict what the change will be. Studies in Central Canada, for example, found that nests in forest patches adjacent to agricultural land had increased predation, while those next to logged areas did not. It appeared that the predator community did not change in the logged areas, while forest patches next to agricultural land had increased densities of red squirrels that preyed on the nests (Bayne and Hobson, 1997). Other studies have shown that songbirds are subject to increased predation along edges, particularly in deforested areas. In other words, the type of fragmentation and the habitat adjoining the fragment influences predator-prey relations. Nest predation is less affected by a single road bisecting an area, but is greatly affected along edges of areas that have been deforested (Tocher *et al*., 1997).

Overall a combination of landscape type and structure, predator community, and level of parasitism are important in anticipating the outcome of fragmentation. For example, unlike studies in the Midwest and Northeast of the United States, where the landscape has historically been patchy, it was found that predation rates actually decreased as human-caused fragmentation increased. This study indicated that the type of predators in an area, as well as the habitat structure were key inputs to anticipate the impact of fragmentation on bird nest predation rates (Robinson *et al*., 1995) .

Not all groups of species experience an increase in predation due to fragmentation. It is found that avian predators were more likely to benefit from fragmentation than mammalian predators (Chalfoun *et al*., 2002). Another study found that turtle nests located along roads had lower predation rates than those located in edges or in forests (Hamilton *et al*., 2002). Fragmentation can also take an indirect toll on plants whose pollinators or seed dispersers are forced to navigate an increasingly fragmented landscape in search of their host plants. In western Australia, only small, isolated populations of the cone-bearing shrub, Good's banksia (*Banksia goodi*), remain, and many of these no longer reproduce because their pollinators have disappeared. Fragmentation often alters animal behavior, due to changes in the environment or predator activity (Davies and Margules, 1998).

4.6. Fragmentation *vs.* connectivity

As fragmentation has an obvious negative influence on habitats and their species, it is necessary to avoid fragmentation, and provide more connections in the environment. Undamaged habitats are likely to control and maintain a microclimate. However, sunlight, logging and other types of disturbances penetrate such habitats and change their microclimate. As a result, species in these habitats will be affected. Efforts must be directed to identify crucial species or group of species as well as the processes that affect them in the habitats if management plans are to be more effective (Noss, 2001).

5. Response of organisms to habitat fragmentation

The effects of fragmentation range from the obvious losses to the more subtle and indirect. Some effects can be repaired. However, most are not being restored or regenerated.

Species vulnerable to fragmentation: Recognizing factors that might make a certain species vulnerable to extinction in habitat fragmentation is one of the most challenging issues in Conservation Biology. Although species vary in terms of vulnerability to predators in fragmented habitats, causes of vulnerability are poorly understood (Webb *et al*., 2002). Studies of Ranius and Hedin (2001) state that a low dispersal rate and range are the reasons that lead to vulnerability of species to fragmentation. Webb *et al*. (2002) explain that habitat specific species are less able to withstand the rapid changes and modifications in their habitats than those who are denoted as generalists species. Therefore, vulnerable species are likely to go extinct. Species differ from each other in respect to vulnerability. Several kinds of species are predicted to be most vulnerable to habitat fragmentation. These may include, the following (Laurance and Bierregaard, 1997): Rare species, wide-ranging species, species with poor dispersal abilities, species with low fecundity, ground nesters and persecuted species.

Rare species: There are two main categories of rare species, restricted geographic distribution (endemic species) and low population densities.

Wide-ranging species: Large species often require large areas for their daily and seasonal movements. They need to travel through fragmented landscapes, facing hazards.

Species with poor dispersal abilities: This refers to species that have low dispersal abilities. Usually, they do not travel far away from where they were born. Roads and clear cuts act as barriers in this situation.

Species with low fecundity: Due to their low reproduction rates, some species. e.g., Neotropical migrant birds cannot quickly rebuild their population when they encounter harsh environmental conditions such as fragmented landscapes.

Ground nesters: Species that nest on or near the ground are more vulnerable to predators than those who nest on or near top of trees.

Persecuted species: Human activities, such as hunting are obvious and higher fragmented landscapes than in forested landscapes because they are easily seen by people.

Initial exclusion: Elimination of species is one of the threats of habitat fragmentation in an ecosystem.

Species that are endemic to a specific habitat type in the landscape are likely to be excluded from their habitat range. For instance, if patches of a certain type are destroyed by fragmentation, species that require these patches are likely to extinct. Local extinctions are expected to be negatively correlated with the patch size as well as the quality of habitat in the landscape (Meffe and Carroll, 1997).

Barriers and isolation: Populations can become isolated within their patches when all of the surrounding habitats are destroyed. Removing these habitats make species migration into different adjacent patches difficult and dangerous. While some species require a single type of habitat to carry out their activities, there are many species that need multiple seral stages to do their activities. Generally, species require a mix of different habitats for various activities e.g., food patches, roost sites, and breeding sites (Meffe and Carroll , 1997). An important factor acting as barriers in fragmented landscape is road construction, where roads divide population into small fragments, exposing them to extinction. Roads contribute directly to the mortality of species when they disperse (Davies and Margules, 1998).

One of the spatial consequences of habitat fragmentation is that fragments become isolated in space and time from other patches of suitable habitat. Isolation disrupts species distribution patterns and forces dispersing individuals to traverse a matrix habitat that separates suitable habitat fragments from each other. While isolation is most often defined by the euclidean distance between habitat fragments, it is, in fact, matrix dependent. An extreme example of this was highlighted by Bhattacharya, *et al*. (2003), who have found that two species of Bombus bumble bees (*Bombus franklini*) would rarely cross roads or railways despite the presence of suitable habitat that was within easy flying range. Some matrix habitats inhibit dispersal more than others and species differ in their willingness to disperse through matrix environments, (Ricketts, 2001). For example, genetic differentiation between invertebrate populations was clearly related to fragment isolation in some studies, but not in others (Krauss *et al*., 2004). Similarly, the relationship between invertebrate species richness and isolation can be positive (Baz and Garcia-Boyero, 1996), negative (Baz and Garcia- Boyero, 1995) or absent (Krauss *et al*., 2003). One likely reason for these conflicting results is that species with different traits differ in their susceptibility to isolation (Laurance and Bierregaard, 1997).

Crowding effects: Crowding occurs usually in the isolated fragments immediately after cutting takes place in the landscape. Logically, when a population is isolated by fragmentation into smaller patches, its intensity is likely to be high when time progresses, leading to congestion (overcrowding) in the population in the isolated patches (Debinski and Holt, 2000). This is an ecological phenomenon known as crowding of the ark. As a result of this phenomenon, a population collapse follows the crowding because of the limited place and the high intense competition among members of the same species on nutrient resources (Meffe and Carroll, 1997).

Climate changes: Fragmentation is considered as a factor that changes microclimate. During the day in a fragmented area, the soil surface absorbs most energy that comes from sun, warming the layer above it. This energy is radiated back during the night. As a result, evaporation, moisture and wind will be changed, which in turn will affect vegetation in the fragmented areas, creating their own microclimate (Smith and Smith, 2001).

Changes in species composition: Meffe and Carroll (1997) mentioned that there are several studies suggesting species composition and abundance will change as fragmentation takes place in landscapes by losing those species that require large areas.

Disturbance effects: Small fragments are more vulnerable to natural disturbances. Post-disturbance succession may be influenced by species invading from the matrix, including exotic species. The disturbance regime itself is altered by fragmentation (Jordan *et al*., 2003).

Behavioral effects: Organisms may change their behavior and/or social interactions if confined to small enough fragments (Primack and Gerwein, 2002).

Anthropogenic effects: Hunters may increase pressure in forest remnants, or humans may otherwise alter ecological processes. Where landscapes are fragmented, species with low dispersal capability may have difficulty responding to anthropogenic climate change. These effects may not occur immediately (Lag effects) and may interact with each other (Synergistic effects) (Laurance, 1991).

Matrix effects: A growing body of evidence suggests that matrix quality is crucially important in determining the abundance and composition of species within fragments (Laurance, 1991). The traditional Island Biogeography Theory approach to the study of habitat fragmentation failed to recognize that the penetration of edge effects from outside a fragment alters habitat characteristics within the fragment and that the matrix may not be completely inhospitable to the fragment dwelling fauna. In fact, there is often substantial overlap between species that inhabit fragments and matrix habitat. This species spill-over is most prevalent in small patches and at the edges of large patches, and may obscure area and isolation effects. Island Biogeography Theory predictions had a better fit when species that occurred in the matrix were removed from the analysis. In addition, increasing species mortality rates in the matrix can have the drastic effect of completely reversing the outcome of competitive interactions within fragments, allowing inferior species to supplant dominant ones within fragments. Generally, some of the matrix effects on biological species are not crossing to adjacent patches, increased risk of predation (e.g. mesocarnivores) and increased exotic species invasions (Cook *et al*., 2002).

6. Management of habitat fragmentation

Habitat fragmentation has a variety of impact on the environment and its organisms. Fragmentation benefits some species, and at the same time put other species at a great deal of risk. As a result, there is necessity to take effective actions to maintain biodiversity in fragmented landscapes.

6.1. Establishment of effective corridors

Inclusion of corridors as a protection strategy in habitat fragmentation is imperative to maintain biological diversity (Rosenberg and Noon, 1997). Corridors function as connection channels between separated fragmented patches (Noss, 2001), so they are crucial in managing habitat fragmentation. Corridors serve two purposes: facilitating movement between various types of patches, including breeding, feeding and birthing; and facilitating immigration and emigration of individuals among such patches (Meffe and Carroll, 1997). Moreover, corridors can improve the population viability in both fragmented and isolated landscapes if they are appropriately designed (Meffe and Carroll, 1997, Noss, 2001).

6.2. Buffer zone

Through well-planned projects, buffer zones provide protection for wilderness from human activities and developments (Meffe and Carroll, 1997). It can increase the ratio of rare and common population by softening the edge effect (Martino, 2001).

7. Conclusion and recommendations

Generally, adverse effects of habitat fragmentation to both wildlife populations and species include increased isolation of populations or species, which leads to: adverse genetic effects; i.e. inbreeding depression (depressed fertility and fecundity, increased natal mortality) and decreased genetic diversity from genetic drift and bottlenecks; increased potential for extirpation of localized populations or extinction of narrowly distributed species from catastrophic events such as hurricanes, wildfires or disease outbreaks; changes habitat plant composition, often to weedy and invasive species; changes the type and quality of the food base; changes microclimates by altering temperature and moisture regimes; changes flows of energy and nutrients and Changes availability of cover and increases edge effect, bringing together species that might otherwise are not interact, potentially increasing rates of predation, competition and nest parasitism. As a result, there is necessity to take effective actions to maintain biodiversity in fragmented landscapes.

8. Acknowledgments

I gratefully acknowledge Arba Minch University, College of Natural Sciences for their support and providing necessary materials for this work. I wish to thank Arba Minch University Natural Science Library workers' and for their help by giving reference materials for this paper.

9. References

Andren, H. (1996). Population responses to habitat fragmentation: statistical power and the random sample hypothesis. *Oikos* 76: 235-242.

Bayne, E.M. and Hobson, K.A. (1997). Comparing the effects of landscape fragmentation by forestry and agriculture on predation of artificial nests. *Conserv. Biol.* 11: 1418-1429.

Baz, A. and Garcia-boyero, A. (1995). The effects of forest fragmentation on butterfly communities in central Spain. *J. Biogeogr.* 22: 129-140.

Baz, A. and Garcia-boyero, A. (1996). The sloss dilemma: a butterfly case study. *Biodiv. Conserv.* 5: 493-502.

Bhattacharya, M., Primack, R.B. and Gerwein, J. (2003). Are roads and railroads barriers to bumblebee movement in a temperate suburban conservation area ? *Biol. Conserv.* 109: 37-45.

Boecklen, W.J. (1986). Effects of habitat heterogeneity on the species-area relationships of forest birds. *J. Biogeogr*. 13: 59-68.

Caley, M.J., Buckley, K.A. and Jones, G.P. (2001). Separating ecological effects of habitat fragmentation, degradation, and loss on coral comensals. *Ecol.* 82: 3435-3448.

Chalfoun, A.D., Thompson, F.R. and Ratnaswamy, M.J. (2002). Nest predators and fragmentation: a review and meta-analysis. *Conserv. Biol.* 16: 306-318.

Collinge, S.K. and Forman, R.T.T. (1998). A conceptual model of land conversion processes: predictions and evidence from a microlandscape experiment with grassland insects. *Oikos* 82: 66-84.

Collins, R.J. and Barrett, G.W. (1997). Effects of habitat fragmentation on meadow vole (*Microtus pennsylvanicus*) population dynamics in experiment landscape patches. *Landscape Ecol*. 12: 63-76.

Cook, W.M., Lane, K.T., Foster, B.L. and Holt, R.D. (2002). Island theory, matrix effects and species richness patterns in habitat fragments. *Ecol. Lett.* 5: 619-623.

Davies, K.F. and Margules, C.R. (1998). Effects of habitat fragmentation on carabid beetles : experimental evidence. *J. Anim. Ecol.* 67: 460-471.

Debinski, D.M. and Holt, R.D. (2000). A survey and overview of habitat fragmentation experiments. *Conserv. Biol.* 14: 342-355.

Diamond, J. (1975). The island dilemma: lessons of modem biogeographic studies for the design of nature reserves. *Biol. Conserv*. 7: 129-146.

Didham, R.K., Lawton, J.H., Hammond, P.M. and Eggleton, P. (1998). Trophic structure stability and extinction dynamics of beetles (Coleoptera) in tropical forest fragments. *Philos. Trans. Royal Soc*. 353: 437-451.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Ann. Rev. Ecol. Syst.* 34: 487-515.

Fahrig, L., Lefkovitch, L.P. and Merriam, G. (1983). Population stability in a patchy environment. In: *Analysis of Ecological Systems: State-of-the-Art in Ecological Modeling,* pp. 61-67 (Lauenroth, W.K., Skogerboe, G.V. and Flug, M. eds.). Elsevier, New York.

Fischer, J. and Lindenmayer, D.B. (2007). Landscape modification and habitat fragmentation: a synthesis. *Glob. Ecol. Biogeogr.* 16: 265-281.

Forman, R.T. (1999). Horizontal processes, roads, suburbs, societal objectives and landscape ecology. In: *Landscape Ecological Analysis: Issues and Applications,* pp. 35-53 (Kloppatek, J.M. and. Gardener, R.H., eds.). Springer-Verlag, New York.

Groom, M.J. and Schumaker, N. (1993). Evaluating landscape change: patterns of worldwide deforestation and local fragmentation. In: *Biotic Interactions and Global Change,* pp. 24-44 (Kareiva, P.M., Kingsolver, J.G. and Huey, R.B., eds.). Sinauer Associates, Sunderland, MA.

Haila, Y. (2002). A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. *Ecol. Appl.* 12: 321-334.

Hamilton, A.M., Freedman, A.H. and Franz, R. (2002). Effects of deer feeders, habitat and sensory cues on predation rates on artificial turtle nests. *American Midland Naturalis*t 147: 123-134.

Hanski, I., Poyry, J., Pakkala, T. and Kuussaari, M. (1995). Multiple equilibria in metapopulation dynamics. *Nature* 377: 618-621.

Hanski, I. (2002). Metapopulations of animals in highly fragmented landscapes and population viability analysis. In: *Population Viability Analysis,* pp. 86-108 (Beissinger, S. and McCullough, D. eds.). University of Chicago Press, Chicago.

Harris, L.D. (1984). *The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity*. University of Chicago Press, Chicago.

Harris, L.D. and Scheck, J. (1991). From implications to applications: the dispersal corridor principle applied to the conservation of biological diversity. In: *Nature Conservation 2: The Role of Corridors,* pp. 189-220 (Saunders, D.A and Hobbs, R.J., eds.). Surrey Beatty and Sons, Chipping Norton, New South Wales.

Hobbs, R.J. (2001). Synergisms among habitat fragmentation, livestock grazing, and biotic invasions in southwestern Australia. *Conserv. Biol*. 15: 1522-1528.

Janzen, D.H. (1983). No park is an island: increase in interference from outside as park size increases. *Oikos* 41: 402-410.

Jordan, F., Baldi, A., Orci, K.M., Racz, I. and Varga, Z. (2003). Characterizing the importance of habitat patches and corridors in maintaining the landscape connectivity of a Pholidoptera transsylvanica (Orthoptera) metapopulation. *Landscape Ecol.* 18: 83-92.

Kindvall, O. (1996). Habitat heterogeneity and survival in a bush cricket metapopulation. *Ecol*. 77: 207-214.

Krauss, J., Steffan-dewenter, I. and Tscharntke, T. (2003). How does landscape context contribute to effects of habitat fragmentation on diversity and population density of butterflies? *J. Biogeogr*. 30: 889-900.

Krauss, J., Schmitt, T., Seitz, A., Steffan-Dewenter, I. and Tscharntke, T. (2004). Effects of habitat fragmentation on the genetic structure of the monophagous butterfly Polyommatus coridon along its northern range. *Molecular Ecol*. 13: 311-320.

Laurance, W.F. (1991). Ecological correlates of extinction proneness in Australian tropical rain forest mammals. *Conserv. Biol*. 5: 79-89.

Laurance, W.F. (2002). Hyperdynamism in fragmented habitats. *J. Veg. Sci.* 13: 595-602.

Laurance, W.F. and Bierregaard, R.O. (1997). *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities.* University of Chicago Press, Chicago.

Laurance, W.F. and Yensen, E. (1991). Predicting the impacts of edge effects in fragmented habitats. *Biol. Conserv.* 55: 77-92.

Levins, R. (1969). Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bull. Entom. Soc. Am*. 15: 237-240.

Lidicker, W.Z. and Peterson, J.A. (1999). Responses of small mammals to habitat edges. In: *Landscape Ecology of Small Mammals,* pp. 211-227 (Barrett, G.W. and Peles, J.D. eds.). Springer-Verlag, New York.

Lindenmayer, D.B. and Nix, H.A. (1993). Ecological principles for the design of wildlife corridors. *Conserv.*

Biol. 7: 627-630.
Lord, J.M. and Norton, D.A. (1990). Scale and the spatial concept of fragmentation. *Conserv. Biol.* 4: 197-202.
MacArthur, R.H. and Wilson, E.O. (1967). *The Theory of Island Biogeography*. Princeton, NJ: Princeton University Press.
Maehr, D.S. and Cox, J.A. (1995). Landscape features and panthers in Florida. *Conserv. Biol*. 9: 1008-1019.
Martino, D. (2001). *Buffer Zones around Protected Areas: A Brief Literature Review*. Electronic Green Journal, NA(NA): NA.
McGarigal, K. and Cushman, S.A. (2002). Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecol. Appl.* 12: 35-45.
McGarigal, K., Cushman, S.A., Neel, M.C. and Ene., E. (2002). *Fragstats: Spatial pattern analysis program for categorical maps.* Comp. software prog. Univ. Mass., Amherst. www.umass.edu/landeco/research/fragstats/ fragstats.html.
Meffe, G.K. and Carroll, C.R. (1997). *Principles of Conservation Biology.* 2nd edn., Sinauer Associate, Inc. Sunderland.
Murcia, C. (1995). Edge effects in fragmented forests: implications for conservation. *Trends Ecol. Evol.* 10: 58-62.
Naiman, R.J., Decamps, H. and Pollock, M. (1993). The role of riparian corridors in maintaining regional biodiversity. *Ecol. Appl.* 3: 209-212.
Newmark, W.D. (1986). *Mammalian Richness, Colonization, and Extinction in Western North American National Parks.* Ph.D. Dissertation, University of Michigan, Ann Arbor, MI.
Noss, R.F. (2001). Beyond Kyoto: forest management in a time of rapid climate change. *Conserv. Biol.* 15: 578-592.
Parker, M. and MacNally, R. (2002). Habitat loss and the habitat fragmentation threshold : an experimental evaluation of impacts on richness and total abundances using grassland invertebrates. *Biol. Conserv.* 105: 217-229.
Primack, R.B. (2002). *Essentials of Conservation Biology.* 3rd edn., Sinauer Press, Sunderland, MA.
Ranius, T. and Hedin, J. (2001). The dispersal rate of a beetle, *Osmoderma eremita*, living in tree hollows. *Oecologia Berlin* 126: 363-370.
Ranney, J.W., Bruner, M.C. and Levenson, J.B. (1981). The importance of edge in the structure and dynamics of forest islands. In: *Forest Island Dynamics in Man-Dominated Landscapes,* pp. 68-95 (Burgess R.L. and Sharpe D.M. eds.). Springer, New York.
Reed, D.H. (2003).Extinction risk in fragmented habitats. *Anim. Conserv.* 7: 181-191.
Ricketts, T.H. (2001). The matrix matters : Effective isolation in fragmented landscapes. *American Naturalist* 158: 87-99.
Ries, L. and Fagan, W.F. (2003). Habitat edges as a potential ecological trap for an insect predator. *Ecol. Entom*. 28: 567-572.
Robinson, G.R., Holt, R.D., Gaines, M.S., Hamburg, S.P., Johnson, M.L., Fitch, H.S. and Martinko, E.A. (1992). Diverse and contrasting effects of habitat fragmentation. *Science* 257: 524-526.
Robinson, S.K., Thompson, F.R. Donovan, T.M., Whitehead, D.R. and Faabrog, J. (1995). Regional forest fragmentation and the nesting success of migratory birds. *Science* 267: 187-190.
Rosenberg, D.K., and Noon, B.R. (1997). Biological corridors: Form, function, and efficacy. *Biosci.* 47: 677-688.
Schmiegelow, F.K.A., Machtans, C.S. and Hannon, S.J. (1997). Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. *Ecol.* 78: 1914-1932.
Schmiegelow, F.K. and Monkkonen M. (2002). Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. *Ecol. Appl.* 12: 75-89.
Schule, W. (1990). Landscapes and climate on prehistory: Interactions of wildlife, man, and fire. In: *Fire in the Tropical Biota,* pp. 273-318 (Goldammer, J.G. ed.). Springer-Verlag, Berlin, Germany.
Smith, R.L. and Smith, T.M. (2001). *Ecology and Field Biology.* 6th edn., An Imprint of Addison Wesley Longman, Inc. San Francisco.
Soulc, M.E., Bolger, D.T., Alberts, A.C., Wright, J., Sorice, M. and Hill, S. (1988). Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands. *Conserv. Biol*. 2: 75-92.
Southworth, J., Munroe, D. and Nagendra, H. (2004). Land cover change and landscape fragmentation: comparing the utility of continuous and discrete analyses for a western Honduras region*. Agri. Ecosyst. Environ.* 101:185-205.
Temple, S.A. (1986). Predicting impacts of habitat fragmentation on forest birds: a comparison of two models. In: *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates,* pp. 301-304 (Verner, J., Morrison, M. and Ralph, C. eds.). University of Wisconsin Press, Madison,
Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler D., Schlesinger, W.H., Simberloff, D. and Swackhamer, D. (2001). Forecasting agriculturally driven global environmental

change. *Science* 292: 281-284.
Tocher, M.D., Gascon, C. and Zimmerman, B.L. (1997). Fragmentation effects on a Central Amazonian frog community. In: *Tropical Forest Remnants,* PP. 124-137 (Laurance, W.F. and Bierregaard, R.O. eds.). University of Chicago Press, Chicago.
Tscharntke, T., Steffan-Dewenter, I., Kruess, A. and Thies, C. (2002). Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. *Ecol. Appl.* 12: 54-63.
Van den Berg L.J.L., Bullock, J.M., Clarke, R.T., Langston, R.H.W. and Rose, R.J. (2001). Territory selection by the Dartford warbler (*Sylvia undata*) in Dorset, England: the role of vegetation type, habitat fragmentation and population size. *Biol. Conserv.* 101: 17-28.
Wallace, J.B., Eggert, S.L., Meyer, J.L. and Webster, J.R. (1997). Multiple trophic levels of a forest stream linked to terrestrial litter inputs. *Science* 277: 102-104.
Webb, J.K., Brook, B.W. and Shine, R. (2002). What makes a species vulnerable to extinction? Comparative life-history traits of two sympatric snakes. *Ecological Research* 17: 59-67.
Weidong, G., Heikkila, R. and Hanski, I. (2002). Estimating the consequences of habitat fragmentation on extinction risk in dynamic landscapes. *Landscape Ecol*. 17: 699-710.
Wiens, J.A. (1994). Habitat fragmentation : island versus landscape perspectives on bird conservation. *Ibis* 137: 97-104.
Wiens, J.A., Crawford, C.S. and Gosz, J.R. (1985). Boundary dynamics: a conceptual framework for studying landscape ecosystems. *Oikos* 45: 421-427.
Wilcove, D.S., McLellan, C.H. and Dobson, A.P. (1986). Habitat fragmentation in the temperate zone. In: *Conservation Biology,* pp. 237-56 (Soule, M.E., ed.). Sunderland, MA: Sinauer.
With, K.A. (1997). Landscape connectivity and population distributions in heterogeneous environments. *Oikos* 78: 51-69.

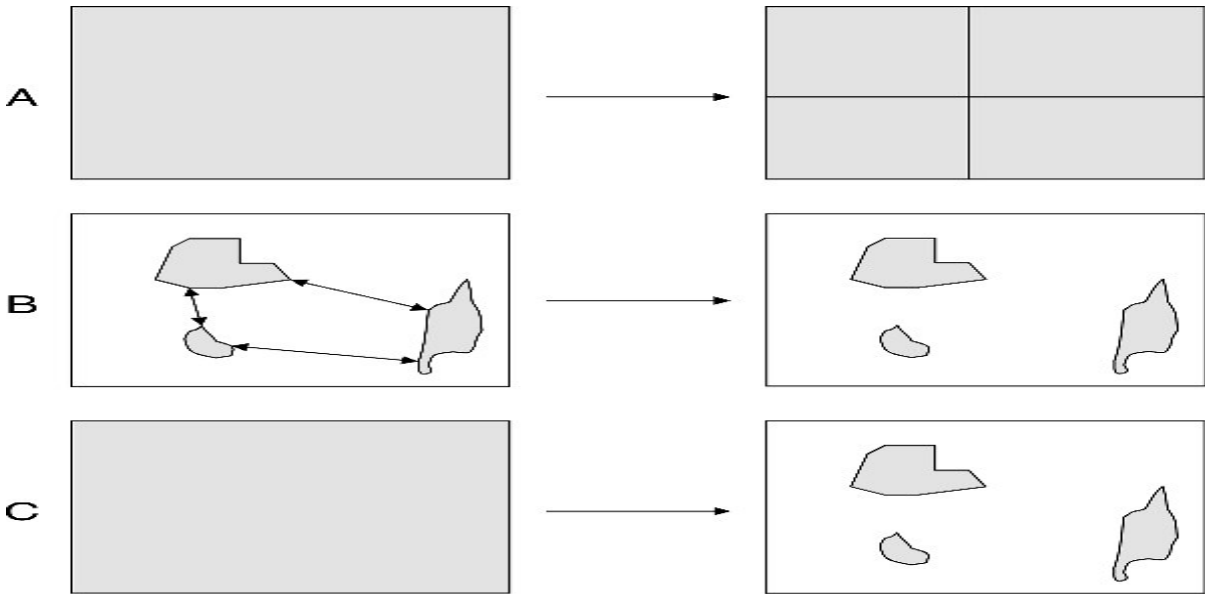

Figure 1. Different types of definitions of habitat fragmentation. Source (Hobbs, 2001).

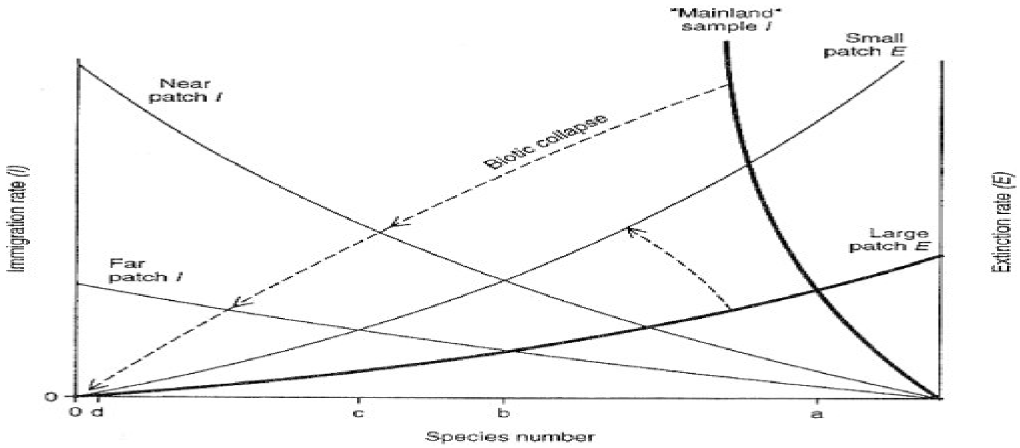

Figure 2. The model of Theory of Island Biogeography (MacArthur and Wilson, 1967).

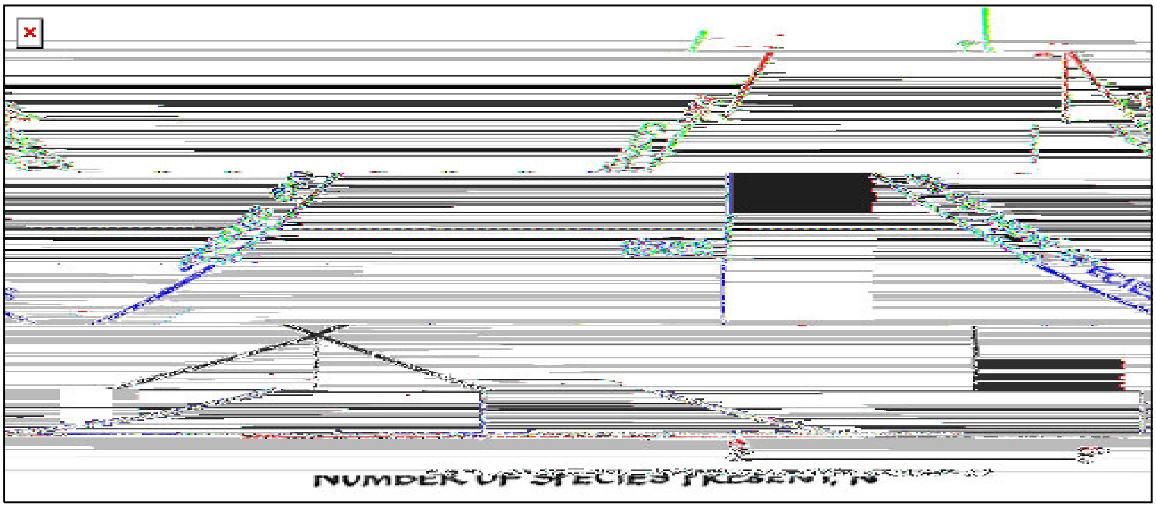

Figure 3. The equilibrium model of Theory of Island Biogeography (MacArthur and Wilson, 1967).

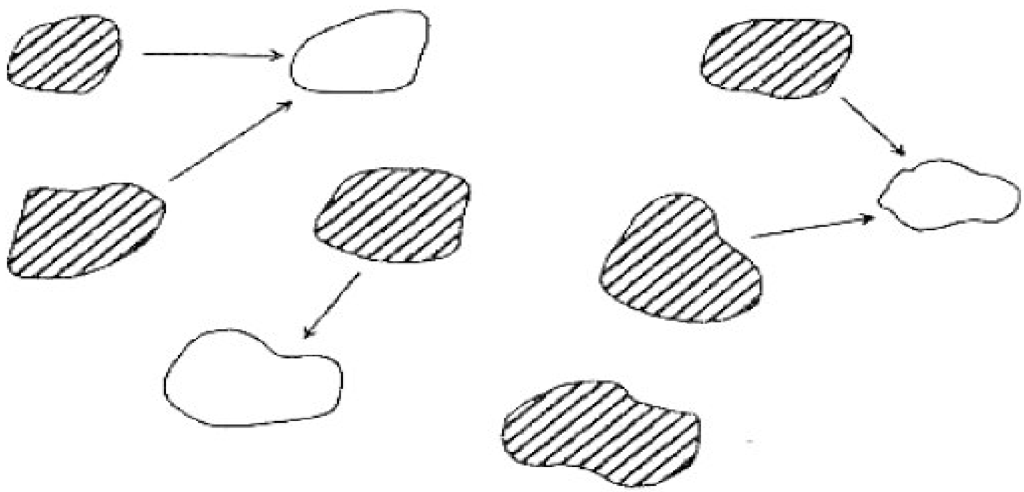

Figure 4. The classic metapopulation model (Collins and Barrett, 1997).