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Processes of Forest Fragmentation ant Its Impacts

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Abstract
Forest fragmentation is a widespread phenomenon and is recognized as one of the major threats to biological diversity. It is a process by which large expanses of forests are converted into smaller tracts of forest surrounded by a matrix of habitats unlike the original in ways that reduce or eliminate the ability of the forest to provide ecological, economic, and social benefits, causing a disruption in continuity of the natural landscape. Natural and anthropogenic factors can lead to forest fragementation. The natural causes include storms, fires and aging. Numerous anthropogenic factors can also account for forest fragementation. Among other things land use, infrastructure construction, urbanization, land tenure and socioeconomic factors can account for forest fragementation. Based on theoretical predictions and small scale empirical studies, forest fragementation is presumed to have a wide range of socio-economic and environmental effects. It can jeopardize goods and services from forests, pose health threat, promote invasive species and threaten biodiversity. Forest fragmentation is presumed to lead to biodiversity erosion via habitat loss, increased edge effects, and negative interactions with species from surrounding non forest patches, the effect of non-random sampling of the original forest, modifying species' population dynamics, altered ecosystem inputs and outputs, increased isolation of forest populations, and invasion by exotic species. Fragmentation can also restrict pollinator movement, which may reduce gene flow and result in increased inbreeding. One of the major outcomes of forest fragementation is edge effect. Edge effects include decreasing humidity and increasing light and temperature which may ultimately affect plant recruitment and survival. In addition, adjacent ecosystems experience flows of energy, nutrients and species across their mutual boundary. As a result, the species composition, structure and ecological processes of an ecosystem near the line of contact with another ecosystem may be changed. Edge effect can also include elevated wind turbulence. Biotic effects can be extremely diverse and include the proliferation of secondary vegetation along forest margins, invasions of weedy or generalist plants and animals, alteration of ecological processes such as nutrient cycling and energy flow.
Keywords forest, fragmentation, biodiversity, biological

1. Introduction

Forest ecosystems, according to Bruna (2004) provide numerous goods and services in addition to housing the majority of the plants biodiversity. Forests are being logged, cleared or otherwise altered by humans at alarming rate. The most dramatic and immediately obvious consequence of deforestation is loss of native habitat in the newly cleared areas. However, not all deforestation results in bare landscapes one normally associates with clear cut logging. In many cases, deforestation proceeds unevenly, leaving a patchwork of forest fragments that are isolated at varying degrees from each other. These fragments of forests are embedded in an intervening habitat known as 'matrix habitat' whose use in intensity varies from regenerating forests, to cattle pasture to human settlement.

Over half of the temperate broad leaf and mixed forest biome and nearly one quarter of the tropical rainforest biome have been fragmented or removed by humans (Wade *et al.,* 2003). Forest fragmentation causes of many conservation problems (Debinski and Holt, 2000 and Pacha *et al.,* 2007). Consequently, the process of forest fragmentation is an issue of primary concern for sustainability and, hence a major concern for the conservationists (Abdullah and Nakagoshi, 2007 and Goparaju, Tripathi and Jha, 2005). This concern centers on the disturbance of once large continuous blocks of forest into less continuous habitat, mainly by human disturbances such as land clearing and conversion of vegetation from one type to another (Franklin *et al.,* 2002). Most forest tree species in the world, Pacha *et al.,* (2007) contend has suffered in the last centuries a continuous process of fragmentation.

According to D' Eon (2002) landscape patterns in managed forests are vital topics in current landscape ecology research and forest management. Interest in forest landscape patterns is mainly fuelled by concern over one of the most important landscape ecology and conservation issues of recent times, habitat fragmentation. In turn, concern over habitat fragmentation is most sensitive among those dealing with forests because of the stern and dramatic effects of forest degradation.

Overall, humans have radically changed the amount, pattern, and composition of global vegetation. Loss of forest and fragmentation of the remainder pose direct threats to biodiversity and imperil the sustainability of ecological goods and services from forestland (Riitters *et al.,* 2000; Lewis and Plantinga, 2004 and Alig, Lewis and Swenson, 2005). Spectacular reduction and fragmentation of forest cover in several parts of the world have provoked many to ask what the impacts of such changes are on species richness, community dynamics and environmental services (Boulinier *et al.,* 2001). This review paper, therefore, intends to realize a better understanding on forest fragementation, its causes and projected consequence.

2. What is forest fragementation?

The fragmentation concept embraces two aspects: (1) reduction of the total area (2) scattering of residual formations in a mosaic in which the remaining individual elements are isolated. The fragmentation concept is scale-free i.e. it addresses no particular scale as it can occur at all scales. This definition addresses no particular kind of habitat since the fragmentation can occur in most types of habitat (Lauga and Joachim, 1992). The concept of fragmentation can be applied to any domain in which continuity is important to the functioning of ecosystems (Pacha *et al., 2007).* Fragementation, according to Franklin *et al., (*2002) can be viewed as both a process (which leads to fragmentation) and an outcome (the state of being fragmented). Fragmentation represents a transition from being whole to being broken into two or more distinct pieces. The result of fragmentation is binary in the sense that the resulting landscape is assumed to be composed of fragments (e.g., forest) with something else (the non-forest matrix) between the fragments. Habitat fragmentation is heterogeneity in its simplest form: the mixture of habitat and non-habitat. The matrix of non-habitat may have a positive, negative, or neutral effect on adjacent habitat. For example, non-habitat consisting of agricultural fields may have a very different effect than non-habitat consisting of younger forest. Similarly, forest fragmentation encompasses two phases. The first phase give rise to the reduction of total amount of forest areas while the second phase leads to the isolation of smaller patches (Goparaju, Tripathi and Jha, 2005). Fragmentation does not necessarily lead to the loss of forestland (Taylor and Kirk, 2007).

In classic view forest fragementation is equated with habitat fragmentation i.e. habitat fragementation was defined as the breaking up of a large intact area of a single vegetation type into smaller intact units. This classic view presents an incomplete view of habitat fragmentation. The key features of the definitions of habitat are that habitat is specific to a particular species, can be more than a single vegetation type or vegetation structure, and is the sum of specific resources needed by a species. Habitat for some species can be a single vegetation type. Nonetheless, habitat can often be a combination and configuration of different vegetation types. An important consideration in both defining and understanding habitat fragmentation is that it ultimately applies only to the species level because habitat is defined with reference to a particular species. Therefore, habitat fragmentation must be defined at the species level and those levels below (e.g., populations and individuals within species). Forest fragmentation would only consider as habitat fragmentation for a species whose habitat was solely defined as interior forest (a single vegetation type) (Franklin *et al.,* 2002).

Currently, forest fragmentation has numerous definitions in the literature. For example Crim (2002) defines forest fragmentation as the breaking up of large, contiguous forested tracts into smaller or less contiguous tracts. Similarly, according to Anonymous (2000), forest fragmentation is a process by which large expanses of forests are converted into smaller tracts of forest surrounded by a matrix of habitats unlike the original in ways that reduce or eliminate the ability of the forest to provide ecological, economic, and social benefits, causing a disruption in continuity of the natural landscape .

Forest fragmentation has its origin as a theoretical suggestion originating from MacArthur and Wilson's (1967) (cited in D'Eon, 2002) crucial work on the theory of island biogeography. It was suggested that residual patches of habitat left from human disturbances such as deforestation were comparable to the oceanic islands used by MacArthur and Wilson (1967) to formulate their theory. In the consequent continental extension of the theory, remnant habitat patches would support fewer species and be more prone to local extinctions, as predicted by MacArthur and Wilson (1967) for small isolated islands the ultimate result being a reduction in biodiversity. However, as we shall see in section-4, this perception i.e. equating forest fragements with islands is being seriously criticized.

3. Causes of forest fragmentation

As described in section 2, fragmentation occurs when an originally contiguous patch of forestland becomes separated into several disjunct patches (Lewis and Plantinga, 2004). This can be caused by anthropogenic and natural events. Some forest fragmentation from natural disturbances such as storms, fires and aging. Mostly, damaging forest fragmentation is caused by anthropogenic activities which are outlined in the subsequent subsections.

3.1 Urbanization and infrastructure construction

Forests may be fragmented by of activities such as road construction and urbanization (Wade *et al.,* 2003; Robinson, 2002; Taylor and Kirk, 2007and Zuidema *et al.,* 1996). As urbanization takes place, natural resources are affected. Majority of urbanization occur on forested and agricultural land. Not only does urbanization result in the direct loss of forestland but it also influences the management of any remaining forestland in a myriad of other ways (Taylor and Kirk, 2007).

3.2 Land use, land tenure and socioeconomic factors

Human induced land-cover, and land-use changes contribute to forest fragmentation (Abdullah and Nakagoshi, 2007 and Butler *et al.*, 2004). Fragmenting the vegetation of a large expanse of forest into isolated pieces by inserting new uses and different mixtures of plants and animals can lead to forest fragementation (*DeCoster,* 2000). Besides, socio-economic and environmental variables such as population density, income, and percentage agriculture can account for forest fragmentation (Butler *et al.,* 2004). An increase in the number of people in an area means that there will be more development and expansion of related land-uses that will be competing with forestry. In general, increased personal income results in lifestyle choices that increase forest fragmentation. As affluence grows, people can more easily afford larger parcels of land on which to build primary or secondary residences (Butler *et al.,* 2004 and *DeCoster,* 2000).

Forests may be fragmented by agricultural activities (Wade *et al.,* 2003; Robinson, 2002 and Zuidema *et al.,* 1996). One of the important causes of forest fragmentation is slashing and burn agriculture carried out by subsistence farmers throughout the tropics. The grasslands resulting due to abandonment of slash and burn agriculture in forested landscapes are also burned annually to promote the growth of nutritious green shoots for cattle. This prevents shrub and forest regeneration and gradually erodes forest margins leading to habitat fragmentation. Because human land uses tend to expand over time, forests that share a high proportion of their borders with anthropogenic uses are at higher risk of further degradation than forests that share a high proportion of their borders with non-forest, natural land cover (e.g., wetland) (Wade *et al.,* 2003). Similarly, Laurance *et al. (*1998) affirm that local factors such as structure of the adjoining matrix habitat may also influence rates of fragment disturbance.

Fragmenting ownership of a large forest tract into several smaller ownerships (also called parcelization) can lead to forest fragementation. For example Butler *et al. (*2004) noted that areas dominated by federal ownership may show significantly different forest fragmentation patterns than areas dominated by private ownership. Increasing the density of people within private forest areas will likely lead to more private forest fragmentation, thereby increasing the importance of less fragmented public forest lands with respect to services such as habitat for wildlife that require large tracts of forestland that are not fragmented.

Kuemmerlea *et al., (*2009) assert that different forest ownership types (e.g., private, communal, or public) are an important aspect of local variations that can result in differing forest use. Landownership type affects, for example, deforestation, forest disturbance, reforestation, illegal logging, and the spatial pattern of forest lands. However, while the pivotal role of land tenure in amplifying or dampening driving forces of forest change is widely acknowledged, no clear patterns emerge about which landownership type is more successful in safeguarding forest ecosystems from unsustainable use. There is growing evidence that the quality and strength of institutions are major factors contributing to forest use patterns. For example, unsustainable forest use and illegal logging in communal forests may be higher when institutions are weak and law enforcement is lacking.

4. Consequences of forest fragementation

Forest loss and fragmentation result in a range of ecological, environmental, social and economic impacts. As outlined in section -2, three distinct changes in forest ecosystem pattern accompany forest fragmentation: reduced forest area, increased isolation of resulting remnants, and creation of edges where remnant forest adjoins modified ecosystems. According to Kupfer (2006)**,** each of these influences a range of population, community and ecosystem processes that may in turn affect biodiversity through reduction of the resource base, population subdivision, alterations of species interactions and disturbance regimes, modifications of microclimate, and increases in the presence of invasive species and human pressures on remnants. Removal and fragmentation of forests has thus been cited as one of the greatest causes of biodiversity erosion. Changes in forest area and spatial configuration also reduce the land base for forest products, and potentially impair the provision of environmental services provided by forests (e.g., clean water). However, some researchers seriously criticize that the effects of forest fragementation are overstated. For example, Kramer *et al., (*2008) contend that forest fragmentation presents a scientific paradox because widely tested theoretical predictions in the fragmentation literature have not been borne out by empirical evidence. In the following subsections, consequences of forest fragmentation based on theoretical prediction and empirical studies are presented. Besides, criticisms on the current forest fragementation paradigm are described.

4.1 Forest Fragmentation as Agent for Biodiversity Erosion and Demographic Changes

The dynamics of populations inhabiting terrestrial habitat fragments have received substantial research attention, including studies of birds, mammals, invertebrates, and plants (Pacha *et al.,* 2007). Forest fragmentation has the capacity to impact habitat quality for more than 80% of all mammal, reptile, bird, and amphibian species. This can result in irreversible changes to biodiversity patterns and richness (Soverel *et al.,* 2009). The following examples are illustrative:

a. Effects on primates

Forest fragmentation can influence abiotic and biotic factors important for the reproduction and survival of animals (Wilder, Abtahi and Meikle, 2005). Several studies have demonstrated that fragmentation of tropical forests reduces primate biodiversity and alters primate demographics and behavior (Goldberg *et al.,* 2008 and Mbora and Meikle, 2004).

b. Effects on birds

In many studies, forest fragmentation has been shown to negatively affect the distribution of breeding birds (Butler *et al.,* 2004). Landscape structure may influence forest bird communities at regional scales through its effects on the total number of species but also on the temporal rates of change in community composition. There are evidences for higher rates of local extinction and turnover in more fragmented landscapes (Boulinier *et al.,* 2001 and Robinson, 1995).

c. Effects on invertebrates

Many animal species are both vulnerable to fragmentation and respond quite rapidly to habitat change. Invertebrate communities, in particular, can change very quickly, both because of their short generation times and because of their small size and ectothermic nature (Debinski and Holt, 2000).

d. Effects on plants

Fragmentation causes a pronounced tree community dynamics. It can lead to elevated tree mortality, damage, elevated wind throw and forest structural damage. Plants that have obligated mutualism with vulnerable pollinators or seed dispersers may also be vulnerable to fragmentation (Santos & Telleria, 1994). At this juncture, it would be essential to ask how does forest fragementation account for biodiversity erosion. Forest fragementation literature put forward a number of factors that are presumed to cause irreversible changes to biodiversity patterns and richness upon forest fragementation. These factors are elaborated in the following subsections.

4.1.1 Effects on genetic processes and reproduction

The restricted size and discontinuity of fragments, according to Aizen and Feinsinger (1994), may impose many genetic effects on plants, both directly and indirectly. Several genetic processes are more or less affected when the populations are drastically reduced and the landscape is fragmented (Taylor and Kirk, 2007 and Pacha *et al.,* 2007). Fragmentation reduces the effective size of the population leading to a higher rate of inbreeding and the reduction of gene flow among populations. These facts determine the loss of genetic diversity of the population and the increase of the genetic differentiation. Nevertheless, these general expected effects cannot always be verified, since they depend on the scale of fragmentation and the biology of the species affected (Pacha *et al.,* 2007).

According to Aizen and Feinsinger (1994), animals impinge on the life cycle of vascular plants at many stages: pollination, seed production (predispersal, dispersal, and postdispersal stages), seedling growth, and maturation. Anthropogenic habitat changes are likely to affect plant-animal interactions at critical life history stages, consequently affecting plant demography and recruitment. Disruption of mutualisms at pollination and seed dispersal stages has been advanced as one of the most threatening consequences of fragmentation to Neotropical forests. Impacts of habitat change on plant-animal interactions may be amplified into long-term effects on the integrity of reserves or other managed landscapes.

Forest fragmentation and the resulting spatial isolation of tree species can modify the activity of pollinators by reducing the density of potential food resources and increasing the distance between those resources. The reduction of floral resources results in longer travel distances between resting and feeding areas and often results in pollinators crossing disturbed areas that are dominated by agriculture. When the distance between plants is greater than the home range of the pollinators, their density will decrease in the disturbed areas and this will result in fewer pollinator visits. Specialist pollinators that are less flexible in exploiting food resources are the most susceptible to local extinction. The effects of fragmentation on pollinator diversity and foraging behavior may have important implications for both the reproductive success and mating systems of the plants they pollinate. Because resources in fragmented landscapes may be less abundant and the distance between resources greater, many pollinators invest more time foraging within the same plant or flower, increasing the level of selfing or reducing seed set in self-incompatible species(Quesada *et al.,* 2004).

One of the more immediate consequences of habitats fragmentation is the disruption of dispersal among populations. Dispersal is a glue that keeps populations together especially in maintaining metapopulation dynamics. Increasing isolation among populations, which leads to reduced dispersal success and patch colonization rates, results in a decline in the persistence of individual populations and an enhanced probability of regional extinction for the entire metapopulation across the landscape? Maintaining landscape connectivity has been identified as the key to preserving dispersal among populations. “Connectivity” is often taken literally to mean the physical connectedness among habitat patches as evidenced by the recommendation and establishment of habitat corridors for the conservation of some species (With, Cadaret and Davis, 1999).

4.1.2 Promoting invasive species

When forest fragmentation patterns exceed the conditions to which native species are adapted, the balance of ecosystems can shift. It then becomes easier for new species to be introduced and become established. Those native and non-native species that are well adapted to these changes in fragmentation patterns will flourish while those less well adapted will be at a competitive disadvantage (Butler *et al.,* 2004 and Taylor and Kirk, 2007). Similarly, Plantinga *et al. (*2007) state fragmentation of forests affects habitat quality and thus increases the likelihood of invasion by exotic species. In some cases, according to Goparaju, Tripathi and Jha (2005), the exotic species which are incorporated into the remaining plant community are responsible for the elimination of the species confined to the forest interior.

4.1.3. Edge effect

One of the major changes caused by forest fragmentation is an increase in the proportion of the edge (Galettia, Alves-Costa and Cazetta, 2003). Forest fragmentation causes changes in physical processes along the edges of the fragments. These changes are described as edge effect. Such changes expose the organisms that remain in the fragment to the conditions of a different surrounding ecosystem (Murcia, 1995). A patch of vegetation whose neighborhood once consisted of similar vegetation now experiences a different, usually more simplified, matrix as neighbor because of edge effect (Aizen and Feinsinger, 1994). Hence, edge effects are the result of the interaction between two adjacent ecosystems, when the two are separated by an abrupt transition.

Edges are presumed to have deleterious consequences for the organisms that remain in forest fragments by causing changes in the biotic and abiotic conditions (Murcia, 1995). Depending on surrounding vegetation, the remaining forest patches are exposed to many factors that cause a huge variability of edge effects, e.g. modified physical gradients, changes in species distribution, altered biodiversity and distortions of many ecological and ecosystem processes (Schessl, Da Silva, and Gottsberger, 2008). However, there is substantial inconsistency among recent studies about the existence and intensity of edge effects. Studies are very site-specific and their results cannot be generalized to produce a universal theory of edges. The current forest fragementation literatures suggest three main types of edge effects that are deleterious to biological diversity. These are abiotic edge effects, direct biological edge effects and indirect biological edge effects.

a. Abiotic edge effects

This involves changes in the environmental conditions that result from proximity to a structurally different matrix. In human-fragmented forests, the fragments are usually surrounded by a matrix of low biomass and structural complexity, such as pastures, croplands or young secondary growth. Differences in structural complexity and biomass result in differences in microclimate. Compared to a forest, crops and pastures allow more solar radiation to reach the ground during the day and higher reradiation to the atmosphere at nights. Consequently, diurnal temperatures in pastures and crops tend to be higher near the ground, and daily temperatures fluctuate more widely. The environment under the forest canopy, in contrast, is cooler, moister and more uniform. The difference in microclimate between the two sides of the edge is likely to create a gradient of temperature and moisture that runs perpendicular to the edge. Air temperature, air moisture, vapor pressure deficit, soil moisture and light intensity vary between the edge and the interior in some forest fragments (Murcia, 1995 and Bruna, 2004).

b. Direct biological edge effects

These involve changes in the abundance and distribution of species caused directly by the physical conditions near the edge (for example, through desiccation, wind throw and plant growth) and determined by the physiological tolerances of species to the conditions on and near the edge. Changes in the physical environment caused by edges may directly affect forest structure (Murcia, 1995 and Bruna, 2004). In rain forests the harsh external climate is buffered by dense canopy cover, but these buffering breaks down near forest edges and may lead to higher mortality of desiccation-sensitive plants. Strong turbulence can result when winds strike abrupt forest edges; increasing rates of wind throw and forest structural damage. Fragmented rain forests often exhibit a proliferation of vines, lianas, and secondary vegetation near edges and some seasonal forests appear highly prone to invasions of exotic plants (Laurance *et al*., 1998).

The creation of an edge increases the incident light which, in turn, promotes plant growth. Thus, even several decades after the creation of the edge, forest structure near the edge remains changed. A variety of tropical and temperate-zone forests shows higher stem densities and basal areas within 20 m of the edge (Murcia, 1995). Similarly, a study conducted by Laurance *et al. (*1998) revealed on average, forest fragments exhibit markedly elevated dynamics, apparently as a result of increased wind throw and microclimatic changes near forest edges. Mean mortality, damage, and turnover rates are much higher within 60 m of edges and moderately higher within 60–100 m of edges than in forest interiors. Less-pronounced changes in mortality and turnover rates are apparently detectable up to 300 m from forest edges.

According to D'Angelo *et al. (*2004), large trees are especially vulnerable to fragmentation, dying three times faster within 300 m of edges than in forest interiors. Elevated tree mortality alters canopy-gap dynamics, promotes a proliferation of disturbance-adapted succession species, reduces above-ground biomass, and accelerates litter production and carbon cycling. At least three factors could increase tree mortality in tropical forest fragments: (1) Microclimatic stresses*:* when an edge is created, some trees simply drop their leaves and die standing, apparently because sudden changes in moisture, temperature or light exceed their physiological tolerances. (2) Wind damage: some trees are uprooted or snapped by winds, which accelerate over cleared land and then strike forest edges, creating increased windshear and turbulence. Wind damage is especially which are poorly adapted biomechanically when exposed to forest edges. (3) Proliferating lianas*:* these structural parasites often increase in density near edges and can reduce tree growth and survival. Further changes, such as increased herbivory or disease incidence in fragmented forests, are also plausible. Likewise, Laurance *et al*., (1998) maintain that the most important proximate cause of elevated tree mortality, damage, and turnover in forest fragments is probably edge effects, particularly alterations in forest microclimate and greater wind turbulence near edges.

Forest fragmentation could be accompanied by inceased litter fall. High litter fall rates are probably due to a pronounced periodicity, edge effects alter litter fall strongly. Litter decomposition and nutrient release are important sources of nutrients in tropical forest ecosystems, where soils are often naturally low in nutrient status. However, thick litter layers may negatively affect the establishment of tree seedlings in shaded understory and cause higher mortality of established seedlings. Seedling mortality in the forest edge is higher than in the interior (Schessl, Da Silva and Gottsberger, 2008).

Some forest plants species show lower densities or are absent near the edge, while others show higher densities, or no changes at all. The different responses among species to the changes in the physical environment at the edge may result in localized shifts in species composition. Perhaps this variability in responses results from the idiosyncratic responses of different species to the physical conditions (direct biological edge effects), to interactions with other species (indirect biological edge effects), or to both (Murcia, 1995).

Forest animal species show diverse responses to the edge. Density and activity of forest animals vary among species from avoidance to preference (Murcia, 1995). Some animal species are strongly influenced by forest structure and microclimate, and a sudden increase in edge vegetation could help drive local extinctions of disturbance-sensitive species in fragments (Laurance *et al.,* 1998).

c. Indirect biological edge effects

These involve changes in species interactions, such as predation, brood parasitism, competition, herbivory, and biotic pollination and seed dispersal. Edge-driven changes in the forest environment and structure may affect the dynamics of species interactions near the edge. For example, a leaf flush that results from increased light incidence at the edge may attract herbivorous insects. These, in turn, may attract nesting birds, which in turn could attract nest predators and brood parasites. Thus, the edge effect on light availability, and on the abundance of herbivorous insects, may initiate a series of cascading effects that can spread across the fabric of the ecosystem through species interactions (Murcia, 1995).

Impacts of forest fragementation on biodiversity

Overall, the possible ways by which fragmentation may lead to biodiversity erosion are well summarized by (Goparaju, Tripathi and Jha, 2005 and Zuidema, Sayer and Dijkmani, 1996). Species found in small patches are not a random subset of the species collection found in large patches, because both patch quality and community structure are altered with the site or geography of the patch. The possible mechanisms that may clarify the process of biodiversity erosion upon forest fragementation are the following. First, the remaining fragments embody only a sample of the original habitat; many species will be eliminated by chance (initial exclusion). The probable reason for this could be the loss of habitat itself. Secondly, the altered landscape in which the fragments exist may be harsh to many native species. Thirdly, small fragments contain fewer habitats and sustain smaller populations of native species, which are thus vulnerable to accelerated disappearance and are likely to cut off the paths of dispersing individuals.

Fragmentation threatens various species in different ways, depending on species-specific characteristics and the type of environment. Fragmentation also affects different species at different life stages. Some species are specialized to the microclimate of the forest, and such species are affected by the fragmentation, since no suitable habitat is available for them as time proceeds and continuous forest are fragmented. Economically and commercially important species undergo higher degree of poaching and extraction, e.g. for food, fuel, timber and medicinal uses. Many forest fragments are readily accessible to humans due to high edge– interior ratios (Goparaju, Tripathi and Jha, 2005).

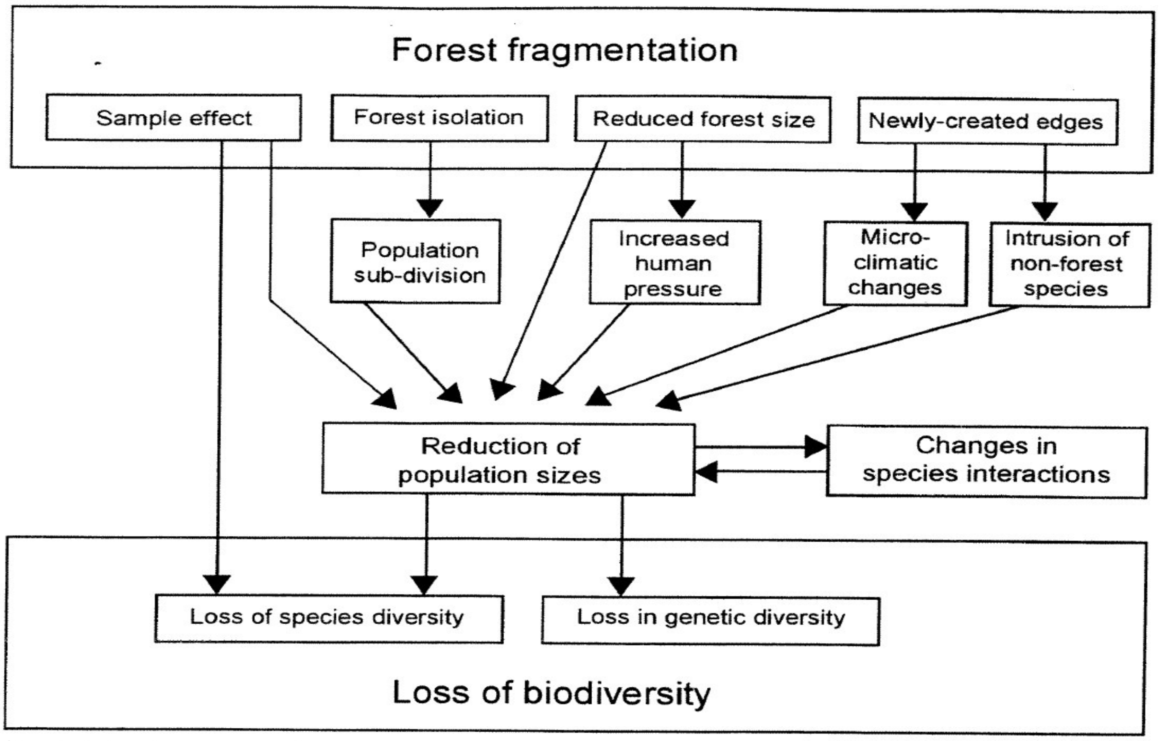

Figure-1: *Schematic representation of the theoretical ways in which four forest fragmentation factors (sample effect, forest isolation, reduced forest size and newly-created forest edges) may cause reduction of population sizes which may result ultimately in loss of biodiversity (Source: Zuidema, Sayer and Dijkmani, 1996)*

At this juncture, it should be noted that some forest fragementation could be worthwhile. According to Taylor and Kirk (2007) types of forest fragmentation that may benefit management include the breakup of an excessively large stand that has little species or age diversity (i.e., the number of different species in a particular area) and/or a lack of species evenness (i.e., the relative abundance with which each species is represented in an area). These stands might benefit from fragmentation that promotes a mosaic of mature, intermediate, and young, mixed species, forest units.

4.2. Jeopardizing goods and services from forests

Forest fragmentation can jeopardize goods and services from forests. An 18-year study of fragmented rainforests in the central Amazon revealed that forest remnants lose substantial above-ground biomass. These losses are caused by sharply elevated rates of tree mortality and damage in fragments, apparently as a result of microclimatic changes and increased wind turbulence near forest margins. As biomass declines near forest edges, emissions of CO_2 and other greenhouse gases in the tropics are probably determined not only by the amount of deforestation, but also by the spatial pattern of clearing, which determines the shapes and sizes of fragments (Laurance, Laurance and Delamonica, 1998). There is concern that continued declines and fragmentation of the forest land base may lead to the impairment of our forest ecosystem's ability to protect water flow and quality, to provide healthy and diverse forest habitat, and to remain a viable economic resource that provides recreation, timber, and other forest products. In other words, forestland base fragmentation leads to sustainable development impairment (Crim, 2002 and Taylor and Kirk, 2007). In general, the overall simplification of biological communities may reduce, and make more costly, the goods and services that humans derive from ecosystems (Plantinga *et al.,* 2007).

4.3 Forest fragementation as health threat

A study of bacterial transmission among humans, nonhuman primates, and livestock in western Uganda revealed that humans living near forest fragments harbored *Escherichia coli* bacteria that were ≈75% more similar to bacteria from primates in those fragments than to bacteria from primates in nearby undisturbed forests. Infectious diseases transmitted among wild non-human primates, humans, and domestic animals pose a serious threat to wildlife conservation, human health, and animal health. For example, outbreaks of Ebola hemorrhagic fever and anthrax have caused epidemic deaths in apes and local humans in West Africa. Emerging pathogens such as these are now regarded as important drivers of primate population declines. Although people and domestic animals have shared habitats with nonhuman primates (primates hereafter) for centuries, the dynamics of these interactions have changed dramatically over the last several decades. Today, most primates live in remnant forest fragments and isolated protected areas within habitat mosaics of farmland, pastures, and human settlements. Fragmentation likely leads to elevated interspecific transmission rates by increasing ecologic overlap among species (Goldberg *et al*., 2008).

4.4 Criticisms on the forest fragmentation paradigm: Quest for solid empirical evidence

As described in the proceeding sections, predicted negative ecological effects of forest fragmentation have been widely cited. Among other things predicted effects involve reduction in patch size, increase in distance between patches, and increased amounts of edge, which ultimately results in species loss, isolation effects such as reduced emigration rates, and edge effects. Though a number of actual and potential effects of forest fragementation is presumed based on theoretical predictions and field studies, there are researchers who contend that most of the impacts of forest fragementation are overstated by the current forest fragementation literature.

D'Eon (2002) argues that most of what we know about forest fragmentation is based on speculation and untested theory due to a scarcity of empirical data. The lack of empirical data can be attributed to (1) the extreme difficulty in conducting good fragmentation studies, and (2) confusion between habitat loss and fragmentation effects. Zuidema *et al*., (1996) state that current knowledge on fragmentation effects is based mainly on studies in small fragments (<10 ha> 8) is by forest fragment. Studies of small fragments cannot be extrapolated to larger sized areas. Hence, empirical data from well-designed fragmentation studies is direly needed to validate theoretical predictions stemming from the fragmentation paradigm. The following are the main sources of criticism on the current forest fragementation paradigm/literature.

a. Forest fragements are equivalent with oceanic islands

As stated in section 2, forest fragmentation has its origin as a hypothetical suggestion stemming from MacArthur and Wilson's (1967) (cited in D'Eon (2002)) work on the theory of island biogeography i.e. remnant patches of habitat left from human disturbances such as deforestation were presumed to be comparable to the oceanic islands used to formulate their theory. In the ensuing continental extension of the theory, remnant habitat patches would support fewer species and be more prone to local extinctions, as predicted for small isolated islands the ultimate result being a reduction in biodiversity (MacArthur and Wilson 1967).

However, according to D'Eon (2002), what makes oceanic islands evolutionarily and ecologically distinctive has little relevance to forest fragments created by human disturbance, and makes the extension of island biogeography theory to continental forests questionable. The most important of these is that unlike the more impassable stretches of water separating islands, spaces between forest fragments in managed forests are, to varying degrees, passable to many organisms and may or may not present significant barriers to organism movement through the landscape. This plausibly creates large differences between connectivity among islands and connectivity among forest fragments and therefore, large differences in the isolation effect of MacArthur and Wilson (1967). Furthermore, the temporal evolutionary forces acting upon species communities on islands cannot be compared to those within temporally and spatially dynamic forest fragments created by human disturbance in managed forests. Much of the early support for predicted biogeographically effects (i.e., effects related to spatial configuration of patches) in remnant habitat patches came from empirical studies demonstrating correlations between lower species richness and smaller forest fragment size in deforested areas. Nevertheless, this consequent species-area relationship says nothing about the effects of isolation, and simply supports the common axiom that habitat area is related to species richness a fact apparently ignored in the fragmentation literature.

b. Impacts of forest fragementation on genetic processes

Kramer *et al., (*2008) insist that the effect of forest fragementation on genetic processes of tropical forests may be overstated. Tropical forest trees evolved in a situation of low densities and large distances between co specifics; their pollination systems essentially involve long-distance pollination. Adaptation to obligate long-distance pollination may make many tropical trees more resistant to genetic isolation imposed by forest fragmentation than temperate trees. Broad generalizations must be evaluated in light of evolution, life history, mating systems, and pollination syndromes forest-by-forest, or even species-by-species, comparisons. Such considerations will provide a more inclusive understanding of forest fragmentation and its consequences.

The population genetics of forest fragmentation, Kramer *et al., (*2008) say, is a thornier issue than simple application of population genetics theory. It is not safe to assume that fragments contain isolated tree populations to which genetic theory of small populations applies. Theory might be relevant to some species, but not at all to many or even most others. It is not safe to disregard the numerous ecological factors altered by fragmentation, what we call fragmentation modifiers, which affect the ecology, demography, and reproductive biology of trees residing in fragments. Pollination and seed dispersal patterns are usually poorly understood in either intact or fragmented forests. Current evidence suggests that long-distance pollination and sometimes seed dispersal prevent genetic isolation in many species. Ecological compensation by members of pollinator or dispersal guilds released from competition, or introduced pollinators and dispersers, may prevent genetic isolation in fragmented stands. At the present state of knowledge there is no justification for expecting unanimously rapid loss of genetic variability in forest fragment stands or for proclaiming genetic processes inconsequential.

c. Confusion between habitat loss and fragmentation effects

The confusion between habitat loss and fragmentation effects, according to D'Eon (2002), is prevalent in the fragmentation literature. Habitat loss concerns the net amount of habitat area lost to a particular disturbance; fragmentation effects, such as isolation and edge effects, concern the spatial configuration of habitat independent of habitat loss. Because the two occur concurrently in practically every case, confusion persists. Prior to a shift from thinking of fragmentation as a combination of both, to thinking of fragmentation as only a spatial configuration phenomenon, much of what was referred to in the literature as fragmentation effects included both habitat loss and fragmentation effects. When the distinction has been made in empirical studies, most fragmentation effects were far outweighed by the effects of habitat loss. Well-designed empirical landscape ecology studies, particularly those addressing fragmentation, are rare (D'Eon, 2002). Hence, in order to clear the aforementioned confusions, such empirical studies are mandatory

Recommendation

- Fragmentation of forest is induced by human activity and natural causes. To decline the human encroachment is one ways of measure to reduce forest fragmentation.
- Forest fragmentation causes serious effects on living things, biodiversity and demographic change.

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