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Habitat Fragmentation and its effect on Aquatic Biodiversity: A Review

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Abstract:

Habitats are dynamic places where organisms live, eat and breed. Aquatic organisms are adapted to their specific habitat for survival whereas fragmentation is a leading threat, causing loss of biodiversity. It results due to anthropogenic activities like construction of Dams, bridges, roads, housing developments, etc. Habitat fragmentation is often a cause of species becoming threatened or endangered due to habitat degradation. Thus, there is an immediate need to conserve the natural ecosystems that will augment aquatic diversity and reduce the extinction rates.

Keywords: Habitat fragmentation, aquatic biodiversity, threatened, endangered, extinct.

Habitats:

Habitat refers to areas that can be used by a particular organism to support survival and reproduction. Wildlife ecologists define habitat as the area where an animal lives, including all resources (both biotic and abiotic) that affect their survival and reproduction (**Krebs, 1985).** Wildlife ecology forms the scientific foundation for conservation and management of wildlife species and their habitats. Habitat is a core concept in wildlife ecology. Every organism has a certain habitat requirement in which it will survive. Some are tolerant to wide variations while others are very specific in their requirements. Species diversity is positively correlated with habitat area (**McArthur and Wilson, 1967**).

Habitats may be terrestrial or aquatic. Terrestrial habitats include forests, grasslands, wetlands and deserts. These broad biomes include more specific habitats with varying climate types, temperature regimes, soil types, altitudes and vegetation types. Aquatic habitats include the fresh water and marine habitats. Fresh-water habitats include marshes, streams, rivers, lakes and ponds. Marine habitats include estuaries, salt marshes, coast, intertidal zone, estuaries, reefs, bays, open sea, sea bed, deep water and shallow water zones.

Habitats are studied at different spatial scales, ranging from microhabitats to macrohabitats (**Doligez T.Boulinier)**. Microhabitats includes factors required to conduct a particular activity by an individual like foraging, reproduction, etc whereas macrohabitats includes all the factors required to support a population of a given organism. Habitat types vary in degree of connectivity and the mechanisms of dispersal utilized by organisms in those habitats. For Example, aquatic systems facilitate passive dispersal of organisms due to the fluidity of the medium. In contrast, movement of microbes may be more restricted within a more solid matrix like soil expected limited dispersal than those in highly connected systems, such as the open ocean **(Hanson et al, 2017).**

Habitat quality influences the fitness of the organisms, hence strong selective pressures promote individuals to choose high-quality habitat for a given activity like foraging, breeding, displaying, etc. Habitat quality is

the contribution of resources for survival and reproduction of individuals and for persistence of populations (**J.L.Rachlow**). Habitat selection is the behavioral and physiological processes by which organisms choose particular areas in which to conduct specific activities (**Stamps, 2008).**

Habitat Fragmentation:

Habitat is a place where plants and animals live in association with their nonliving counter parts (**Fahrig, 2019).** It refers to the division of habitat into smaller or isolated fragments (**Fahrig, 2003).** It results in habitat loss and change in the configuration of habitat causing discontinuities or fragmentation in an organism's preferred environment. It is currently one of the main threats to terrestrial and aquatic biodiversity (**Connor and McCoy, 2017).**

Fragmentation of aquatic habitat causes population fragmentation and ecosystem decay affecting species abundance and decline in the global aquatic biodiversity. It leads to both habitat loss and habitat disintegration, both of which affect biodiversity (**Benton et al., 2003**). For many species, populations scattered in space are prone to extinction **(Fahrig and Merriam, 1994**) if the networks of patches are not sufficiently connected by dispersal (**Bowne and Bowers, 2004).** Anthropogenic disturbance such as agricultural expansion accompanying climate change has resulted in global habitat loss and fragmentation. This requires to increasing our ability to manage landscapes effectively to improve species conservation efforts into the future (**Jordan and LacherJr, 2018**). A fragmented landscape is characterized by a strong contrast between vegetation patches and their surrounding matrix, commonly occurring in formerly forested areas (**Fischer and Lindenmayer, 2007).** It has been shown that fragmentation of Tropical Rain Forests has had serious impacts on remaining intact old-growth tropical rainforests, including changes in forest structure, ecosystem dynamics, and ecosystem function **(Guirado et al, 2006).** For instance, chronic increases in tree deaths along the edges of habitat patches cause gaps in the canopy, bringing changes to forest structure and species composition. Such fragmentation has severely damaged the biodiversity of these rain forests. It is estimated that already one million species from Tropical Rain Forests are forced to extinction because of land-use changes within the last 100 years. Many animals, are highly sensitive to the size of forest fragments that compose their habitat. Once isolated, small habitat fragments lose species at extremely high rate. Local bird and butterfly extinctions (extirpations) have been shown to occur more rapidly in small (1–10 ha) than in large (100 ha) fragments of TRF **(Brooks et al, 1999).** Forest edges dry out more easily, leading to the spread of fires, such as lightning strikes, that would usually die-out in the damp interior of a Tropical rain forests **(Flaspophler et al, 2001)**.

As human land-use begins to dominate a region, the natural habitats eventually collapse. In addition to threatening the size of species' populations, habitat fragmentation damages species' ability to adapt to changing environments. This happens at the genetic level, as it interferes with gene flow from one generation to the next, in small population. In large populations, genetic mutations and recombination have a greater chance of survival in the species' gene pool whereas in smaller populations, mutations can bring about the expression of lethal genes leading to extinction of species preventing natural selection from working. One aspect of this is the phenomenon of genetic drift causing change in the genetic composition of a population due to chance or random events, rather than by natural selection **(Mech and Hallett, 2001).** It results in changes in allele frequencies over time. In small populations, genetic drift results in some traits becoming more common while others become less common over time, but random events drive these changes, not natural selection. Genetic uniformity (as found in small populations) makes populations more vulnerable to high infection rates and rapid spread of diseases. It also reduces a population's ability to respond to environmental change through the process of adaptation. Because of reduced gene flow, the chances that local adaptations can spread throughout the whole species are also reduced (**Elias, 2018).** Landscape features and geomorphological constraints dictate where and how far individuals can move in all ecosystems thus affecting species coexistence and local community structure (**Altermatt et al., 2011**). The aquatic habitat destruction and loss is where the aquatic environment is unable to support life due to degradation. This is a process that is contributed by various natural and human activities **(ThibaultDatry, 2017).**

Aquatic Habitat Fragmentation:

Healthy and diverse aquatic habitats indicate healthy and diverse populations of aquatic organisms including fish. Aquatic habitats are natural materials comprising of rocks, coral, gravel, sand and mud, type of vegetation (macrophytes, snags, seaweeds, seagrasses, mangroves and saltmarsh), shape and nature of habitat (pools,

riffles, reefs), or the overall ecosystem (wetlands, floodplains, streams, estuaries, lakes, beaches). Different species have different habitat requirements and these may change throughout a fish's life. Aquatic habitat includes water to be the right type (freshwater, estuarine or saltwater), temperature, quantity (depth and flow) and quality. Fragmentation plays a key role in both terrestrial and aquatic ecosystems, including freshwater, estuarine and marine systems (e.g. oceans, coral reefs and seagrass meadows) causing a serious threat to the aquatic ecosystem (**Ledger et al., 2011**).

Human activity has accelerated the rate and extent of fragmentation in freshwaters, particularly by over-use of water by the growing populations (**Vörösmarty et al., 2010).** Also, climate change causing hydrological droughts via reduced rainfall in many areas (**Poff and Zimmerman, 2010**), are potentially causing widespread habitat loss and fragmentation. During droughts, river flows decline, reducing the volume of wetted habitat (water width and depth) and altering habitat structure, increasing water temperature, reducing dissolved oxygen and altering nutrient supply (**Dahm et al., 2003**). This unpredictable drought fragmentation can have devastating effects on aquatic food webs **(Aniela Chamorro et al, 2015**).

Marine systems such as oceans, coral reefs and seagrass meadows are also exposed to fragmentation. For example, the open ocean might appear to be relatively homogenous, but there are distinct vertical and horizontal regions separated by physicochemical barriers, such as pycnoclines and frontal systems, which are more permeable to larger organisms (e.g. anadromous and catadromous fishes) than to the smaller organisms.

Coral reefs experience increased rates of habitat loss and fragmentation due to excessive fishing (**Raymundo et al., 2007**), and coral bleaching is occurring with increasing frequency due to rising sea temperature (**Oliver and Palumbi, 2009**). The loss of structural complexity in these fragmented coral landscapes results in declining abundances and diversities of reef fish and mobile invertebrates **(McClanahan1, 2007).**

Other marine systems include seagrass meadows, which form unique, productive and diverse ecosystems (**Duarte and Chiscano, 1999**). They are affected by fragmentation through dredging and boating effects, eutrophication, extreme weather events, urchin grazing and wasting disease (**Orth et al., 2006**). Fragmentation of seagrass meadows impacts on epifaunal diversity and abundance, can lead to rapid declines in species diversity and abundance (**Reed and Hovel, 2006**).

Other major marine habitats influenced by fragmentation include kelp forests, salt marshes and sea ice. Habitat loss in kelp forests reduces biomass and abundance of fish (**Deza and Anderson, 2010**). The die-off of salt marshes results in changes in the behaviour of key grazers (snails) as they seek shelter from predation by blue crabs (**Silliman et al., 2005**). Increased fragmentation of sea ice habitats results in declines in mating success and searching efficiency of top predators such as polar bears (**Sahanatien and Derocher, 2012**) and in changes in phototrophic community structure and relative abundance of dominant marine taxa.

Effect of Aquatic Fragmentation:

Effect on Fish Food: Fish food includes aquatic plants, like seagrasses, macroalgae (seaweed), plankton (microscopic animals and plants), invertebrates like mosquito larvae, dragonflies, water beetles, boatmen, shrimp, mayflies, and other fish (**Cadwallader et al**, **1980**). Fish food have habitat requirements of their own. So, changes in habitat might not affect the fish directly but might affect their food source. This, in turn, means that the fish cannot survive in that habitat (**Yeager et al, 2016**).

Places of Fish Shelter: Aquatic animals like fish needs shelter to hide from predators, also to protect itself from extreme conditions such as flood flows and harsh sunlight. In freshwater, patches of vegetation, areas behind rocks, around submerged logs and branches (snags), provide fish with places to shelter. In estuaries, seagrasses and mangrove forests provide shelter for fish from predators. If these shelters are removed from fish habitat, then they become vulnerable to predators ***(Kevin et al, 2021).*** Also, marginal plants provide important habitat for both invertebrates and vertebrates, and submerged plants bring about oxygenation of water, absorb nutrients and play a part in the reduction of pollution (**Jeffrey et al, 2020).**

Fish Movement: Most Fishes travel a great distance to swim from one area to another. Habitat fragmentation due to construction of barriers, such as road crossings, weirs, dams or floodgates, can block fish movement. This can have devastating impacts on local populations of fish (**Koehn and Nicol, 1998).**

Places to breed: Fishes have a tendency to breed in the the running waters of the streams and rivers. Hinderences in the runnig water cause failure of fishes to breed. For many freshwater fishes, breeding is triggered by rising water temperatures and increase in day length. Processes that alter the natural water temperature of a stream, such as release of cold water from the bottom of dams during summer, can prevent fish from breeding (**Gehrke et al, 2002).** Also**,** construction of dams in the path of a river alters the running water of a river into a stagnant water of a pond. Fishes adapted to breed in running water do not breeding the stagnant waters.

Fecundity: Fishes are specific about the habitat on which they lay their eggs. For instance, some native fish lay their eggs in hollow logs or aquatic vegetation. Some, like the freshwater catfish, make a nest from gravel. Anthropogenic interference can inundate the breeding grounds of most fishes **(O'Connor and Koehn, 1998).**

Causes of Aquatic Habitat Fragmentation:

The causes may be Anthropogenic or Environmental.

i. **Anthropogenic Factors:** Human activities for agriculture, like construction of dams, bridges, roads, housing developments, etc. urbanization, population explosion, harvesting natural resources - for industrial production, etc.

ii. **Environmental Factors**: Climate change, floods, droughts, volcanoes, etc.

Construction of Dams on rivers (Barriers): Dams have changed the morphology, hydrology, and function of many freshwater ecosystems, thereby causing major shifts in species distribution and abundance, including extinctions (**Dudgeon et al, 2006**). Construction of dams in the route of a river converts the running water of a river into a stagnant water of a man-made lake. The dams and reservoirs can increase energy production, but at the same time fragment and change river systems, and potentially threaten the fisheries. The planned construction of 38 hydropower dams have impacted the fish species inhabiting freshwater ecosystems in the megadiverse African country of Gabon. **(Cutler et al, 2020)**

Construction of roads and bridges: Transportation infrastructure contributes towards fragmentation causing habitat loss by forming a barrier to the movement and dispersal of many species (**Mader, 1984)**. Furthermore, traffic associated with the infrastructure causes an increase in the mortality risk for fauna, which adds to the fragmentation effect. (**Trombulak and Frissell, 2000**)

Climate changes: Habitat change may be directly driven by climate. Habitat fragmentation and climate change impacts interact in freshwater systems. For instance, deforestation increases solar radiation input on freshwater systems, which can elevate temperatures in streams or small lakes in deforested environments. Increased solar incidents in these environments can also increase UV exposure in freshwater organisms, further increasing their vulnerability to thermal effects. Climate change is expected to exacerbate both drought periods and intensive storm events because of an enhanced hydrologic cycle coupled with warming. Lakes frequently dry out in periods of drought and fill in with sediment as they age. Extended periods of very long droughts had profound effects on lake levels, salinities, and habitats (**Herrera et al, 2020**).

Pollution

There are some human activities which are responsible for the changes in the marine ecological conditions and such may mean alteration or destruction and loss to the marine habitat (**Ghosh et al, 2020)**. Water, air and soil pollution can intoxicate the environment and make the water contaminated. Thermal pollution, a result of industrial activities also destroys marine habits resulting in the depletion of marine animal and plant species **(Mullu, 2016)**.

Lack of protection from the governments

A higher probability of negative impacts on the aquatic biodiversity exists when the government fails to acknowledge the importance of conserving the natural habitat. When there are no policies regulating access to marine areas, sea plants and animals will be affected (**Wilkinson et al, 2018**).

Development of coastal places

Due to the development of the social economy, many countries develop their coastal regions for water transport. But in the process, less concentration is rendered on the need to conserve the natural marine habitat. Coastal reclamation activities have rapidly increased throughout coastal regions and have a significant negative impact on fish habitat fragmentation. As a result, the environmental factors of ichthyoplankton spawning and nursery grounds have changed drastically, which has profoundly affected the biomass and biodiversity of ichthyoplankton **(Guo and Jiao, 2007).**

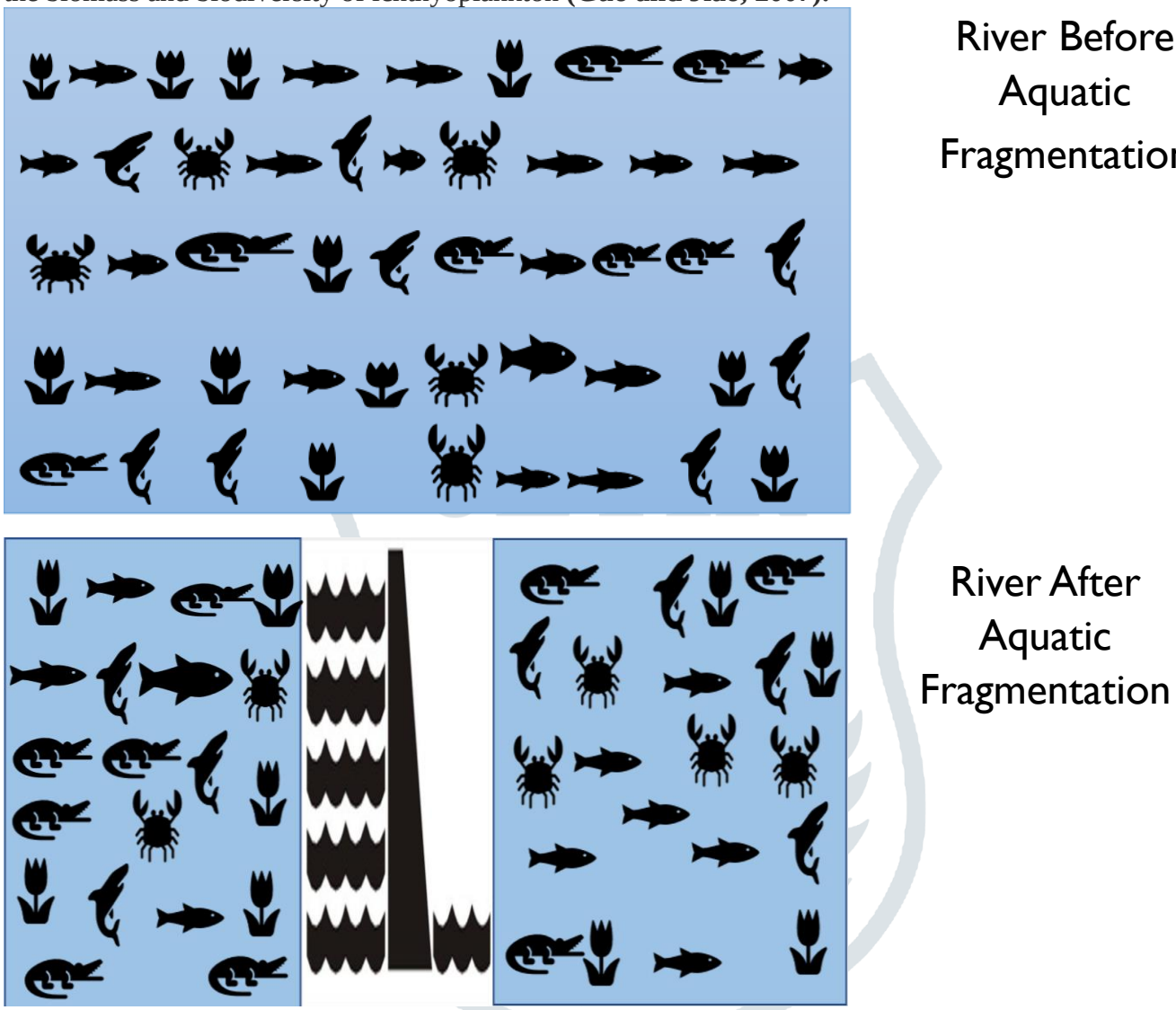

Figure: A diagrammatic representation of a River before and after river Fragmentation. Construction of Dams in the path of the river results in aquatic habitat fragmentation which in turn affects species abundance, causes extinction and loss of biodiversity.

Impact of Habitat Fragmentation

1. Alters aquatic ecology affecting water quality, quantity and breeding grounds; create artificial types of aquatic environment (**Rands et al, 2010**).

2. Nutrient Depletion causing stunted growth, diseases and parasite infestation and increased mortality. (**Irfan and Alatawi, 2019**).
3. Blocking migration routes **(Hughes et al, 2005**).
4. Changing from lotic to lentic water (**McGarigal et al, 2002**).
5. Large populations are converted into smaller population. (**Dudgeon et al, 2006).**
6. Formation of smaller populations: Inbreeding reducing species fitness, Reduction in Genetic Diversity causing Genetic Drift.
7. Affects Adaptations and Animal behaviour **(Lessmanna et al, 2016).**
8. Climate Change (**Craig, 2012**).
9. Local population extinctions and loss of biodiversity: Animals such as whale, shark and many others depend on other aquatic animals for food. Extinction of one means the extinction of the others in the food chain. The whole consequence of the marine habitat loss and destruction is that it leads to death and migration of animals. Some plants also die and become extinct due to the extreme ecological conditions.
10. Most of these species cannot adapt to a highly fragmented or altered landscape, and the few that do adapt often come into conflict with humans by feeding on crops or livestock.
11. Rapid land conversion rate: Where marine habitat loss and destruction is characterized by the disappearance or the decrease in the water masses, there is a quick land conversion rate.
12. Loss of coastal natural beauty: when the natural habitat is encroached or even destroyed, such species or animals and plants become extinct. The extinction takes away the beauty of the coastal areas.
13. Socio-economic impact on human beings.
14. Food reduction.
15. Crowding effects: Crowding occurs usually in the isolated fragments immediately after cutting takes place in the landscape. When a population is isolated by fragmentation into smaller patches, leading to congestion (overcrowding) of the population (**Debinski and Holt, 2000**).
16. Inter-dependence between the terrestrial and aquatic lives results in food depletion. For Example: Humans depend on some sea fish such as octopus, star fish, salmon, etc for food. When they are depleted, humans will definitely suffer from that negative impact.
17. Low oxygen concentration: When aquatic habitat is destroyed the major impact that acts as the determinant is that oxygen concentration in water is lowered that it can barely support aquatic life.
18. Migration of marine animals: Some animals may be forced to migrate.
19. Loss of revenue to the governments: Coastal regions are major tourist attraction sites. Whenever such animals and plants are rendered extinct, resulting in decrease in tourism activities and loss in revenue.
20. Damage the ability for species, such as native plants, to adapt effectively: Smaller population prevents gene flow from one generation of population to the next. Whereas, for species of larger populations have more genetic mutations which can arise and genetic recombination impacts which can increase species survival in those environments.

Conclusion: ***Conservation and Restoration measures:***

Habitat conservation and recovery planning are essential to protect endangered species:

1. Survival habitat should be designated to prevent delay and allow immediate action to protect endangered species. (**Van Horne, B. 1983)**
2. Creating Awareness**:** Civic Education by respecting the laws of nature, treating plants and animals with care may create awareness about the importance of natural habitat and biodiversity **(Díaz et al, 2020)**
3. Role of individual for protecting the ecosystem **(Chan et al, 2016)**
4. Protecting remaining intact sections of natural habitat (**Wood et al, 2018)**
5. Development of buffer zones around fragmented habitats in order to protect those natural habitats.
6. Legal action. **Warren, 1996**
7. Reducing human populations.
8. Environmental Conservation Policies: Environmental conservation bodies such as UNEP creates laws to control industrialization and waste disposal by various countries. **Keith et al 2015**
9. Reducing climate change and Controlling Pollution: Water, air and soil pollution are responsible for the adverse climatic changes. Controlling environmental pollution can be the remedy. **Stralberg et al, 2020**
10. Restricting over aggressive coastal developments: Policies to be formulated to support and give guidance needed to be done during coastal urbanization to preserve the marine habitats. (**Tscharntke et al, 2012)**
11. Limiting land conversion drive.
12. Using designate routes during shipping: Countries using water transport can use designate routes to limit the danger caused oil spill disasters and other heat related dangers by ships.
13. Landscape Connectivity and Creation of corridor linking habitats: Habitat continuity could influence dispersal (**Lindström and Langenheder, 2011**). In river systems, (**Carrara et al., 2012**)., the unidirectional downstream movement of water down river networks carries materials and promotes dispersal of individuals in the downstream direction. Therefore, landscape connectivity and its effects on populations and communities in dendritic networks require a reconsideration of the notion of patch isolation, fragmentation, and connectivity (**Fagan, 2002**). The creation of corridors linking habitats has been suggested as a way to help some species, especially migratory ones to flourish.
14. Before any of the proposed dams are constructed, we recommend conducting baseline surveys of the fishes present at the dam site and urge that dams not be constructed in areas that may affect dispersion of marine-associated fishes. We also recommend that existing dams within regions of high suitability for marine-associated species, particularly the dam at Kinguele on the Mbei, be outfitted with fish passages appropriate to migratory species in the area or water management strategies to ensure minimum environmental flows that mimic natural conditions. These actions should help to minimize negative impacts of dam development on fish biodiversity and fisheries production.

These Measures will help to reduce the loss of biodiversity due to habitat fragmentation.

Future Directions:

Habitat fragmentation will change the genetic and functional diversity of ecosystems over long duration which inturn will provide low-quality services such as reduced productivity, and carbon retention by an ecosystem. **(Laurance et al., 2006).**

Suggestion:

The habitat diversity hypothesis proposes that large areas have a greater variety of habitats resulting in increase in species richness as compared to small areas thus indicating the existence of species–area relationships **(Connor and McCoy, 2013).**

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