THE ROLE OF FORESTS IN THE PRESERVATION OF BIODIVERSITY

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Summary

Forests embody much of Earth's ecosystem, species and genetic diversity. Genetic diversity is particularly high in many forest tree species, and its loss, though not often noticed, may have far reaching impacts. Species and ecosystem diversity generally increase with temperature and rainfall, and three broad-scale forest zones can be defined on the basis of climatic conditions: tropical, temperate and boreal. Each of these major forest ecosystem types consists of many finer scale ecosystems. Tropical forest hosts fantastic levels of species and ecosystem diversity, but harvesting pressures are threatening many species today. Effects of forest fragmentation, introduction of exotic species and climate change all influence forest biodiversity patterns and quantity. In many areas, particularly in temperate and tropical zones, little intact forest remains, and forest dependent species have disappeared, or exist only in isolated fragments and heavily modified landscapes. Montane forests are of particular concern, because they

commonly host a diversity of endemic species, which are unable to migrate to other appropriate habitats as the climate warms.

1. Introduction

Forests are complex biotic communities, characterized by trees, and encompassing much of the life on Earth. They constitute the world's largest and most important terrestrial ecosystems, and have the largest reservoir of plants and animals on land. Even the simplest forests consist of unnumbered co-existing life forms, from soil microbes and arthropods in the litter layer to lichens, and *Lepidoptera* that adorn the higher branches of the forest canopy. Tropical forests alone are thought to host more than 50% of the world's biodiversity. A high proportion of species are still undiscovered, many of which are likely to live in tropical forests.

Forests, particularly in the tropics are also under great threat. In 1995, Kimmins, a forest researcher in British Columbia, Canada, noted that the projected annual rate of increase in demand for forest products worldwide, would be approximately equal to the annual allowable cut in the Canadian province of British Columbia. Thus even if forest harvesting were consistently carried out in a sustainable manner today, a new area the size of British Columbia would have to be found each year to sustain the projected harvest of the future. Globally, much of todays logging is not carried out in a sustainable manner.

Significantly, the areas with the highest biodiversity are also those under greatest threat. It is estimated that 2/3 of the world's terrestrial biota exists in forests, and the greatest proportion of the terrestrial forest biota live in tropical forests. Almost one-tenth of the trees themselves are considered to be threatened with extinction. Forested land is steadily converted to other uses, or is so badly disrupted by harvesting activities that it will become scrub or semi-desert. In some parts of the tropics, it is estimated that forests are being destroyed at a rate as high as 2% per year. Hence, the role played by forests in preserving biodiversity is shrinking daily.

Forest ecosystems change constantly, sometimes through periodic catastrophic disturbance that completely changes the structure of the ecosystem, and which can indeed creates a new ecosystem, with a largely new cast of species. Other forest ecosystems remain essentially stable for many centuries under natural conditions, with changes occurring on a much smaller scale, perhaps a tree falling or a small group of trees falling, due to localized insect or disease outbreak. Some life forms are essential for continued existence of a particular ecosystem; others are opportunists, present because of ephemeral conditions.

Humans have used the forest in all parts of the globe for millennia, and have had rapidly increasing impacts on forest ecosystems during the past few centuries, as population size and technological sophistication have increased. Fire has been used extensively by forest-dwelling humans to improve conditions for game, and to clear land for agriculture. Forests that appear natural today in Asia, Africa or South America, may in fact have been actively farmed for thousands of years. Humans were one of the multitude of species manipulating other species to shape the forest for their best use.

Until recent centuries, in most parts of the globe, humans were simply one of many large forest species, but with a greater capacity for influencing biodiversity than other species had. In tropical areas, humans are thought to have contributed to the high species diversity through agroforestry. Now the human species threatens the continued existence of forest ecosystems in many areas of the world.

Unlike some other major ecosystem types, such as oceans or deserts, a forest ecosystem is characterized by its dominant life form. The structural elements that define a forest are, or were, living. Thus the role of forests in preserving biodiversity is at once a trivial and a hugely complex question. The visual structure of a forest is made up of trees, of different sizes and usually different species. The tree species themselves usually represent highly diverse gene pools. With changing environmental conditions such as climate, elevation, and soil fertility, and with changing developmental stages, the composition and structure of forest ecosystems change. So the variety of forest ecosystems across a landscape constitutes an additional layer of biodiversity.

All forests are not equally biodiverse. Generally, species diversity increases with temperature and rainfall amount. In the northern hemisphere, genetic diversity also tends to increase going south. Plant species diversity has been found by some scientists to decrease with increased soil fertility. There are many exceptions to this trend however, as patterns of biodiversity are influenced by a number of factors. No one factor is adequate to explain the shifting numbers of species or levels of genetic diversity either at a local or global scale.

2. Levels of diversity

Biodiversity is the variety of life in all of its forms – ecosystems, species, genes and the processes that maintain them. There are many reasons to preserve biodiversity at each of these levels. Recent studies examining the question of the influence of diversity on ecosystem stability show that within an ecosystem, and across a range of different ecosystem types, increased diversity tends to be positively correlated with ecosystem stability. The rationale for this can be called the "insurance hypothesis", meaning that the functional redundancy of species and the ability of different species to respond differently to different conditions provide a buffering effect for the ecosystem. The relationship between species richness and ecosystem functioning is not uniform across ecosystem types, however, as it depends on interspecific interactions. The relationship is strongest in species-poor environments or where environmental conditions are variable in time and space, and species are adapted to particular environments with little broad overlap.

2.1. Genetic diversity

Genetic diversity is inherited variation within and among individuals within species. It is the result of differences in gene coding, originating from mutations, and maintained in populations by selection, migration, and chance. Most genetic mutations are deleterious, causing an enzyme system or other protein component to malfunction. Individuals carrying such mutations may be maladapted. Other variants may be neutral under current conditions, acquiring a positive or negative value if particular conditions change. Occasionally, mutations give rise to variants that are particularly adapted to current conditions, conferring selective advantage.

Genetic diversity has been described as a matrix with four columns and thousands of rows. The columns correspond to the different levels of genetic diversity within species: diversity within an individual, diversity within a population, diversity among populations within regions and diversity among regions. The rows would be the traits that characterize a species. These traits could be specific DNA sequences or observable (phenotypic) characteristics. Most measures of genetic diversity are based on molecular traits, such as DNA segments or enzyme forms. There is little evidence that these traits are related to adaptive traits. Thus, most genetic diversity studies to date are barely scratching the surface and may be telling us little about the adaptive potential of populations or species.

Genetic diversity is as important as species diversity in maintaining ecological processes. Forests are incredible repositories of genetic diversity. Individuals of a given species may appear to be uniform, but in many cases there is a great deal of variability. Almost all tree species are highly variable genetically, especially widespread, long-lived, wind-pollinated species. Tree species with widespread distribution and late successional status generally maintain most of their variability within populations, and there is often little difference among populations. Species with insect pollination instead of wind pollination, and particularly those with isolated patchy occurrence, often exhibit more genetic variability among populations.

Most genetic diversity within a species may be captured by a relatively small number of individuals, but rare alleles can be lost, unless the population size is large, simply because of sampling effects. All variants begin as rare alleles. Thus, population size is an important determinant of a species' evolutionary potential. Pre-adapted variation refers to the existence of random variants that, by chance, have genetically controlled characteristics predisposing them to survive a particular shift in biotic or abiotic conditions. Large, genetically diverse populations of any species maintain a plethora of variants, some of which are advantageous in the present environment, many of which are presumed to be neutral, and some that are mildly deleterious under present day conditions. It is impossible to predict which variants may become important in different environments. In the face of rapid and catastrophic environmental change, resulting from high CO_2 levels, the importing of exotic diseases, parasites, herbivores or predators, the widespread loss of forests, desertification, or changing temperatures, the survival of species may depend upon the existence of particular pre-adapted variants in existing populations.

Genetic diversity is necessary to allow evolutionary processes over the long term, whether or not widespread catastrophic changes occur. Sufficient genetic diversity must exist within populations to ensure the potential for adaptation to gradual changes. Stability of populations and ecosystems may depend on genetic diversity in so far as genetic diversity buffers populations in the face of unpredictable environmental changes.

Most forest harvest practices still result in dramatic swings in local population size and the age class structure of forest trees. Leaving low numbers of parents after a partial cut may result in elevated levels of inbreeding, reducing survival, growth and fecundity of the offspring. In addition to ensuring that population size is sufficient and that the population achieves reproductive success, the density of seed trees retained after a partial cut must be sufficient to avoid inbreeding beyond a natural background level.

Much less is known about the genetic diversity of other species constituting a forest ecosystem, as trees, particularly commercial species, have received much more scientific scrutiny than other species. It does seem safe, however, to assume that the genetic diversity of many species depends upon the continued existence of large and intact forests.

2.2. Species diversity

Biodiversity is often considered synonymous with species diversity for several reasons. First, species are the most recognizable unit in a continuum of diversity in nature. Arguably, populations can be reconstituted by breeding for a suite of characteristic traits, and an ecosystem can be restored to some semblance of its original condition as long as the species are still available. When a species goes extinct, however, it is gone forever.

The concept of species has been the subject of much debate over the years, because in spite of the practical appeal of classifying organisms into discrete groups, there are many exceptions to the rules. There are two primary concepts of species, both of which generally arrive at the same classification. The first is the standard definition: an interbreeding group of organisms that cannot exchange genes with other organisms. The second concept of species derives from phylogeny. A species is a phylogenetic group with a single source. This concept avoids the difficulties that arise with species that clearly interbreed, yet as a group, retain their integrity, as well as species that do not breed, but instead reproduce through asexual means. Regardless of the definition, and even in the absence of any formalized set of rules, classification exercises generally yield similar results. Thus, species is the logical basic unit of biodiversity.

Species diversity may be measured and presented in a variety ways. Species richness, or alpha-diversity, measures the number of species in an area, as a simple presence/absence count. Another measure examines evenness, taking into consideration abundance as well as number of species. In this measure, an ecosystem with a flat species frequency distribution would be considered more diverse than one with the same number of species, but with a few species dominating while others are present in very low numbers. Taxic diversity takes into account the evolutionary pathways and degrees of relatedness of taxa. Using this measure, an ecosystem hosting two tree species, each from 15 families would be considered more diverse than one with five species from each of six families.

Tropical forests are estimated to be home to at least two-thirds of the world’s species. This is in spite of the fact that these forests cover only about 7% of the Earths land surface. Dry tropical and temperate forest ecosystems consist of lower numbers but still a high proportion of the species in a given area. Boreal forests are less species diverse than temperate forests but still account for more species than other ecosystems at the same latitude. For example, in Canada, forests cover approximately 40% of the land area, but include about two-thirds of the species native to the country.

In tropical forest, the local areas with the highest diversity of tree species also generally harbor the highest diversity, or at least very high diversity of other principal groups of forest species. This can be explained in terms of “environmental volume”. When a forest is stratified into different tree height and shrub layers, there are many niches available for other species to use.

Recent studies show that the most productive ecosystems are often those with the highest species diversity. This is probably not a simple cause and effect relationship. Rather, it is more a feedback loop with high biological diversity contributing to innate site productivity. Other things being equal, the more species in an ecosystem, in general, the more resistant it is to drought and other kinds of environmental stresses.

For years, scientists have debated the relationship between species diversity and ecosystem stability. There is now little doubt that declines in the number of species will increase the rate of simplification of ecosystems. Recent evidence indicates that, in general, diversity can be expected to give rise to ecosystem stability. The relationship between diversity and stability apparently depends on the strength of interactions between species within a community. Decreasing diversity is expected to increase the strength of interactions between species, thus increasing the probability that communities will experience destabilizing dynamics and, possibly, ecosystem collapse.

2.3. Ecosystem diversity

The third level of biological diversity is, in common parlance, ecosystem diversity. An ecosystem is a functional unit consisting of interacting biotic and abiotic components. Ecosystem diversity as a measurable entity is highly dependent on scale. A decomposing tree stump or a tiny pool in a forest may be considered an ecosystem. Earth in its entirety is the most complete functioning ecosystem. Between the two extremes lies an endless array of ecosystem sizes, complexities and compositions.

Ecosystems are poorly understood in comparison with species and genes. In contrast to species, ecosystems are not clearly delimited. Genetic diversity may be technically difficult to measure, but given the tools, there is little argument about what is actually being measured. Ecosystems, on the other hand, rarely have clear physical boundaries. A further difficulty in assessing ecosystem diversity is the requirement for a frame of reference that is larger than the ecosystems themselves. The frame of reference tends to be completely arbitrary, following political boundaries for example.

Even if certain ideas about ecosystems are agreed upon, for example, scale may be at the landscape level and forest ecosystems may be roughly equated to forest types, there would still be problems in defining ecosystems because of the plethora of approaches to vegetation classification. Ecosystem is a much wider concept than community, which is sometimes used interchangeably as if the two terms were synonymous, so equating forest ecosystems with forest types is problematic. The concept of ecosystem includes the abiotic as well as biotic components of a system, whereas “community” refers to a characteristic biotic association.

Assessment of ecosystem diversity requires classification of ecosystems. Various approaches have been taken to such classification. Most use vegetation as a primary factor. Ecological land classifications, such as many of those in use in the U.S. and Canada, generally use a combination of climate, physiography, landform, soils and potential vegetation.

Some classifications are based solely on vegetation. The rationale for this is that vegetation patterns can be considered to integrate and represent a variety of abiotic factors. For example, in the U.S., the national vegetation classification system developed by the Nature Conservancy and adopted by government agencies is hierarchical with physiognomic levels similar to the UNESCO hierarchy and two additional floristic levels: alliance and association. Association refers to a plant community type with uniform habitat conditions. The alliance is a physiognomically uniform group of associations with one or more dominant or diagnostic species. At the alliance level there are more than 2 000 recognized forest and woodland ecological units. This represents a minimum of 2 000 forest ecosystem types in the US, a small fraction of the global forest ecosystem diversity.

The different approaches to ecosystem classification have developed due to different objectives. Biotic-abiotic, terrestrial-aquatic integration is necessary for an ecosystem approach to classification. Understanding ecological dynamics at all levels is undergoing rapid growth, setting the stage for more accurate and comprehensive ecosystem classifications.

3. Forest ecosystems and biodiversity

Global forests vary from dense, tropical, highly diverse rain forests to low-diversity sub-arctic forests such as the black spruce of boreal Canada or dryland scrub (for example the high-elevation piñon pine forests of Mexico). Each of these can be considered as large-scale ecosystem types and each includes a diversity of species, genes and smaller-scale ecosystems. Boreal, temperate and tropical forests each consist of a variety of forest ecosystems. The amount of biodiversity reflected by numbers of species and genetic variation within species, as well as the variety of ecosystems varies greatly from extreme northern or southern latitudes to the equator.

3.1. Boreal

Boreal forest is the world’s largest vegetation formation, and exists as a circumpolar band between tundra in the north, and temperate forests to the south. Boreal forest covers about 33% of the global forest area and includes less than 60 tree species that are considered to have commercial value. Another 60 or more tree species are considered to be significant, constituting smaller components of the boreal forest. Compared with other forest ecosystems however, diversity of tree and other associated floral and faunal species is low. Conifer tree species dominate boreal forest, but of 69 conifer genera worldwide, only eight are found in boreal forest. Though species richness is low in boreal forests, functional diversity is high, with few species in each functional group. This means that a change in a few species can have a serious impact on ecosystem function.

Boreal forests are relatively uniform throughout the circumpolar band, so ecosystem diversity is relatively low. Most boreal tree species, however, have high genetic diversity. They are out-crossing, wind-pollinated and generally very widespread. Each of these factors correlates positively with high within-species genetic diversity.

Major threats to boreal forest ecosystems include over- or inappropriate harvesting, air pollution, and climate warming. The high frequency of each tree species constituting boreal forest means that tree species extinction is not a serious concern, but regionally, large-scale exploitation threatens ecosystems. A number of lichen and *Lepidoptera* species are considered endangered in boreal Scandinavia. Species diversity decreases with latitude in the boreal forest, with the most northern forest ecosystems consisting of one or two tree species and relatively low numbers of species of shrubs, mosses and lichens. Associated faunal diversity similarly declines with latitude.

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Biographical Sketch

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