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"TO STUDY THE RELATIONSHIPS AND IMPACTS OF FOREST BIODIVERSITY, CARBON AND OTHER ECOSYSTEM SERVICES"

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Abstract: Biodiversity underpins many ecosystem services, one of which is carbon sequestration, and individual species' functional traits play an important role in determining ecological processes. Higher levels of biodiversity generally support greater levels of ecosystem service production than lower levels, and ecosystem properties, such as resilience, are important considerations when managing human-modified ecosystems. Tropical forests have high levels of biodiversity yet have experienced severe impacts from deforestation and degradation, with consequent losses of biodiversity and ecosystem processes that support the provision of ecosystem services, including carbon storage. Tropical Montana and dry forests are especially vulnerable. In (sub-)tropical forests recovering from major disturbances, both carbon and biodiversity increase, but recovery rates diminish over time, and recovery of biodiversity is typically much slower than that of carbon. However, (sub-) tropical secondary forests are recognized for their biodiversity conservation values and as important carbon sinks. In many cases, anthropogenic factors such as land use change, introduction of species or barriers to dispersal can lead to the creation of 'novel ecosystems' that are distinct in species composition and functioning. The implications of these novel ecosystems for conserving ecological integrity and provision of ecosystem services remains poorly understood.

KEYWORDS: Biodiversity , ecosystem, services, tropical forest, values.

INTRODUCTION

A sound understanding of how *ecosystems*[1] function and the role that *biodiversity* plays in these functions is essential for the management of forests. The ecology of forest systems as it applies to the relationship between biodiversity and *ecosystem services* is discussed, with an emphasis on species, ecosystems and carbon. The first section outlines key concepts necessary to understanding the links between biodiversity and ecosystem services, including *carbon sequestration*. This relationship is examined with respect to how carbon accumulates and is lost from terrestrial ecosystems with a focus on tropical and sub-tropical forests. The main (sub-)tropical forest types are presented, including their values in terms of carbon and biodiversity.

THE RELATIONSHIP BETWEEN BIO- DIVERSITY AND ECOSYSTEM FUNCTIONING

People often think of biodiversity as a list of species with- out necessarily considering the roles that species perform in ecosystems. However, in recent decades, there has been an improved understanding of important linkages between species and the way that ecosystems function (1). While recent studies show that diversity of *native species* enhanced grassland productivity more than *introduced species* diversity , there is growing recognition of the importance of species traits rather than identities, to the provision of services, suggesting that some '*novel ecosystems*' (2) comprised of new species assemblages may function adequately. Therefore, the functional argument for biodiversity conservation does not necessarily depend on reinstating previous ecological conditions; although provisioning, cultural, aesthetic and other benefits or services are often enhanced by native biodiversity.

BIODIVERSITY AND ECOSYSTEM RESISTANCE AND RESILIENCE

The ability of an ecosystem to withstand environmental change, maintain its structure and composition of species (i.e., its state), and support the provision of *services* consistently over time is referred to as '*ecosystem stability*'. The term 'stability' encompasses a suite of measures including the ability of a sys- tem to remain unchanged in the face of chronic perturbations (i.e., '*resistance*') and its ability to return to its original state after being altered (i.e., '*resilience*') although with considerable variation in rates of processes over time. In forests, stability varies among types and especially over space, but usually refers to the recognisable mix of dominant tree species (3).

Resistance refers to the capacity of the system to maintain its state under chronic small-scale perturba- tions. Some studies have suggested limited or no rela- tionship between resistance and *species diversity* (4), others have suggested a positive effect. Differences in population responses across species may produce an averaging effect that stabilises overall com- munity functioning (5). Hence any effects of increasing biodiversity on resistance may be ecosystem-dependent and are uncertain.

Ethiopian montane forest with tree ferns.Photo © Christine B. Schmitt

There is, however, a positive relationship between diver- sity (genetic, species and landscape-level) and ecosystem resilience (i.e., recovery after a major disturbance) (6). It is likely that functional diversity, not total species richness, is most relevant to ecosystem resilience. Forest resilience is of particular interest owing to current *climat* of their responses and the number of species (6). Diverse forests are generally more resilient than forests with lower diversity, on similar sites . This resilience is, in part, because interactions within communities play a key role in determining the stability of the ecosystem as a whole such as via redundancy in food web interactions. Catastrophic impacts on ecosystems following large disturbances can be mitigated by ensuring diversity at landscape scales, since different stand types will exhibit different levels of *vul-nerability* . These findings suggest that the structure of entire landscapes should be considered for ecosystem manage- ment in order to maximise spatial and temporal insurance (7). Finally, ge- netic diversity can also provide a considerable contribution to ecosystem resilience . Thus, resilience is an emergent property of forest ecosystems conferred at mul-tiple scales, through genetic, species and landscape heterogeneity (8).

ECOLOGICAL THRESHOLDS AND SAFEOPERATING SPACE FOR MANAGEMENT

Environmental change and human activities that cause local extinctions of species and alter key ecological pro- cesses may destabilise a forest ecosystem. For example, loss of species in systems can have large consequences that result in *trophic cascades*, significantly altering ecosystem structure and function (9). Of- ten, ecosystem responses to environmental change may be undetectable until an *ecological threshold* is passed, resulting in non-linear and unexpected changes that may be irreversible. Over long enough time periods or under human manipulation, ecosystems move to alternate stable states that reflect new environmental conditions and may be difficult to recover, as will undoubtedly be the case under current climate change . Managing ecosystems within a 'safe operating space' ensures that they do not reach such irrevers- ible levels of change. There are many examples of forest recovery to new states following *degradation* and these 'novel' systems may or may not provide the same ecosys-tem goods and services as past forests (10).

THE RELATIONSHIP BETWEEN FOREST AREAAND BIODIVERSITY

Several models and theories have helped to improve our understanding of the relationship between biodiversity and land use change (11), has been widely applied to predict biodi- versity losses driven by deforestation. The 'species-area model' has undergone some recent improve-ments to better reflect real land use changes. In particular, the differential responses of species to the landscape ma-trix (i.e., land uses that have replaced original forests), the effects of *forest fragmentation* and *edge effects* can now be modelled and predicted. These theoretical considerations for- malise the almost ubiquitous observation that large con-tiguous forest areas contain more biodiversity (especially species) than smaller and isolated stands. This pattern, coupled with current knowledge on the relationships be- tween biodiversity and the provision of ecosystem goods and services, including carbon storage and sequestration, reinforces the value of con-serving or restoring large areas of forest to improve miti-gation of forest biodiversity loss, and conservation and enhancement of *carbon stocks*

THE RELATIONSHIP BETWEEN BIODIVERSITY AND ECOSYSTEM

There are four broad categories of ecosystem services: provisioning, such as production of fibre, food and wa- ter; regulating, such as climate regulation, erosion control and pollination; supporting, such as nutrient cycling, soil formation and primary productivity; and cultural, such as spiritual and recreation benefits (34). Biodiversity is related to the provision of many of these services and *biomass* production in forests. The economic value of these services has been quantified in some cases, for example, the global biologi-cal control of crop pests by natural enemies is estimated to be worth USD 4.5 billion per year (Losey and Vaughan, 2006). Other services, however, such as regulation of erosion and water purification are only weakly related, or unrelated, to species diversity but rather depend on the type of ecosystem and its condition (Table 1).

A general characteristic of ecosystem services that are strongly related to biodiversity is that the key processes occur at local scales (e.g., pollination, biological control of pests, soil formation), whereas ecosystem services and goods to which biodiversity contributes less (e.g., water quality, erosion control, oxygen production) tend to operate at larger landscape to regional scales. biodiversity and provide the agents necessary for certain ecosystem services, such as pest control and pollination, thereby resulting in both sustainable agriculture and forestry (12). In contrast, large-scale intensive land conversion for timber, pulpwood or agricultural crops can degrade natural ecosystems (13).

Table no.1 Species richness and biodiversity relationship to ecosystem services

Ecosystem service	Mechanism/management effects onservice	Relationship w/species richness
Erosion control	Coverage of soil surface; soil retention on slopes (Pimentel et al. 1995)	None to low
Nutrient cycle	Photosynthesis, nitrogen fixation, food-web,decomposition (CO_2 is not included here - Vitousek andSanford, 1986; Bonan and Shugart, 1989)	medium to high
Natural hazard prevention: flooding	Interception of rainfall and evaporation of wa-ter infiltration by soil (FAO and CIFOR, 2005; Guillemette et al., 2005; Bruijinzeel, 2004)	None to low
Air quality regulation	Air filtration by plants (Givoni, 1991;Weathers et al., 2001; Bolundand Hunhammar, 1999)	Low
Climate regulation	Regulation of moisture in air, prevention ofgreenhouse gas emission (e.g. Houghton et al., 2001; Bolund andHunhammar, 1999)	Low
Water purification and freshwater supply	Purification from polluted/contaminated tofresh water (Neary et al., 2009; Foley et al. 2005; Postel andThompson, 2005)	Low
Disease regulation	Vector regulation, relative (lower) density ofhost in ecosystem/ community to regulate density of pathogens (LoGiudice et al., 2003)	High
Cultural services including cultural diversity and identity, recreation and ecotourism, and education	Provisioning of landscape (scenery);Symbolic (flagship) species	High but different locally
Food, fibre, timber production	Harvest and cultivation	Low to high
Pollination	Pollen transfer by animals (insects, birds) (e.g. Ricketts, 2004); forest habitat required forpollinators and depends on movement capabil-ity and landscape pool of pollinators (Kremen et al., 2004;Tscharntke et al., 2005;Tylianakis et al., 2008)	High
Biological pest control	Requires habitat for natural enemies (Landiset al., 2000), predator diversity can depend onthe environmental context (Terborgh et al., 2001;Tylianakis et al., 2008;Tylianakis and Romo,2010)	High
Seed dispersal	Fruit feeding and dispersal of seeds, usually by birds or mammals (Tscharntke et al., 2008); diversity of dispersers can improve provision ofthis service (Garcia and Martinez, 2012).	None

BIODIVERSITY AND CARBON SEQUESTRATIONAND STORAGE IN FORESTS

While a positive relationship between tree species richness and above-ground productivity has often been found (14), this relationship is not universal. Nevertheless, a majority of the studies assembled suggested a positive relationship between species richness and some aspect of forest *production* or respiration, and found a positive relationship in multiple studies via meta-analysis. There are also non-linear landscape level effects because changes in ecosystem processes are affected by the fragmentation of forests and edge effects that exacerbate species loss, population decline and eco- system functioning (15).

The majority of studies have not distinguished the effects of species composition on productivity and other ecosystem functions, from the effects of species richness or individual species. However, a significant positive effect of species composition, but not of species richness, was found for litter decomposition rates in rainforests Bycontrast, a greater effect of species richness than species composition was reported in a natural tropical forest in Panama (13). The latter study reported that differences in plant species richness were more important in explaining patterns of carbon storage (16). In relatively simple forest systems, individual species may dominate processes, and in complex systems, certain species and *functional groups* are often particularly important in controlling specific processes. Greater clarification of the importance of individual species effects, and the role of functional groups for carbon storage is an important area for further research.

BIODIVERSITY AND CARBON IN MAJOR (SUB-) TROPICAL FOREST TYPES

Different definitions and measurements of (sub-)tropical forest area and types render a detailed comparison across studies difficult. Crucial methodological differences are related to the identification of woody land cover other than natural forest and the use of different tree cover thresholds (between 10 and 40 percent) that influence the estimation of extent, especially for (sub-)tropical dry forests and savannahs (17) . Furthermore there are many other different global ecosystem classifications, such as the Global Land Cover 2000 classes. There is broad consensus that species richness is generally highest in tropical rainforests compared to all other (sub-)tropical forest types. However, species richness is only one aspect of biodiver- sity, and it is crucial to consider species composition, spe- cies distributions and the differences in species composi-tion across similar forest types but in different regions of the world.

Perhaps the best available data are for birds, which indicate that 32, 24 and 15 percent of global endemic avian species occur in tropical lowland moist, tropical montane moist and tropi-cal dry forests, respectively . Many (sub-)tropical forest areas are recognised as global biodiversity 'hotspots' because they feature exceptional concentrations of endemic species and are experiencing exceptional loss of *habitat*. For example, Hubbell et al. (2008) suggested that there are over 11,000 tree species in the Amazon region, but at current rates of deforestation, forest degradation and climate change, at least 1,800 to 2,600 species are predicted to become extinct in the next few decades. In fact, habitat change and loss are the major reason for all groups of species to be listed as vulnerable and endangered on the IUCN Red List of Threatened Species. (Sub-) tropical moist montane, (sub-)tropical moist lowland and (sub-)tropical dry forests contain the greatest percentage of species affected for all taxa (18)

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