

# Emerging Threats to Forests: Resilience and Strategies at System Scale

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## ABSTRACT

Forests provide multiple ecosystem services that are critical to sustain societies and ecosystems. Protecting the forest systems become imperative as human demand for forest products and services increase. In addition to current stressors, several emerging threats pose serious implications on the survival and sustainability of forest ecosystems. These include climatic change, invasive species, natural disasters, land use change, and pest/diseases that can severely impact the ability of forest to sustain ecosystem services. There is a need for using a systems-based framework to increase resilience of forest systems to cope with these threats. We review literature on these threats and propose a systems-framework for forest resilience. While strategies for each threat are often easier, comprehensive strategies that can handle multiple threats and specific to forest type is required. There is also a need for further research into forest resilience and landscape-scale response and resilience.

**Keywords:** Forest; Resilience; Systems; Emerging Threats

## 1. Introduction

Forest is a type of habitat or biome which has high density of trees [1]. The FAO [2] defines forest as a land with tree crown cover of more than 10% and are of more than 0.5 hectare. The forest is in fact a complex ecosystem with distinct interrelationships of nonliving organisms (the plant, animals, and microorganisms) and the nonliving, inorganic or abiotic part (soil, climate, water, organic debris, rocks) of an environment. Over 30% of the Earth's surface is covered with forests in modern times where as once they covered 50% of total surface of the world. This reduction is mainly because of deforestation caused by the human need for wood, food, and housing [1].

Improvement of forest management and increase in forest cover will potentially reduce the negative trend of the forest surface and provide many goods and services to human life. Forest services such as soil and water conservation, conservation of biological diversity, improvement of human living conditions through recreation and employment opportunities, and protection of natural and cultural heritage are observed worldwide [3].

The classification of forests into managed and natural types depends on the stress placed on forests by direct human intervention [4]. Forests are classified in many

ways. They have been classified according to the biome in which they occur, combined with leaf longevity of the dominant species *i.e.* whether they are evergreen or deciduous. Another classification is based on composition, predominantly of broad-leaf trees, coniferous (needle-leaved) trees, or mixed types. United Nations Environment Program—World Conservation Monitoring Center divides the world's forest into 26 major types, which reflect climatic zones as well as the principal types of trees. These 26 forest categories are used to enable the translation of forest types from national and regional classification systems to a harmonized global one that include two forest types called as “temperate and boreal forest” and “tropical forest” [1].

The development of the main systems of vegetation classification based mainly on climatic factors is described and physiognomic, floristic and ecosystems are highlighted [3]. According to the FAO, in the year 2001 [5] the world's forests cover 3.87 million hectares with an observed negative trend in the last two centuries. The balance between the annual rate of deforestation (14.6 million hectares) and forest increase (5.2 million hectares) is mainly attributed to tropical and non-tropical forest loss [3]. Major factors leading to forest loss are habitat loss and degradation, invasive alien species, overuse of resources, and pollution. Due to the complexity of these

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factors, various approaches and strategies are being used to reduce biodiversity loss. All, however, require the best available scientific information that allows the development and implementation of sound management strategies [6].

Forests are increasingly being managed for multiple uses and values, and they play multiple roles that include climate change mitigation, habitat provision, biodiversity support, and conservation of soil and water resources. Sustainably managed forests also contribute significantly to local and national economies and to the well-being of current and future generations [7]. Forests cover defines the quality of a landscape and contribute to a vital part of heritage and to rural economy. While the benefits of forests are clear, there are emerging threats to forests that expose these resources to rapid exploitation and loss. There is a need for a renewed thinking on protecting forests exposed to emerging threats like urbanization, invasive species, climatic change, natural disasters, and new pests or diseases. We argue for a systems-based approach to manage forest cover with a focus on increasing resilience of the system that will allow forests to adapt to these emerging threats.

## 2. Benefits Uses Value of Forests

Forests are a home to millions of people and comprise the richest biodiversity among terrestrial ecosystems. Tropical forests cover some seven percent of the Earth's surface, and contain 50 percent of all known species of the world. Forests also provide ecological and environmental services which include watershed and soil protection, and climate regulation through carbon sequestration. Forests are also perceived to have intrinsic value and in many cases are vested with profound spiritual and cultural value, in addition to economic and scientific importance to local communities. These benefits accrue through the existence and continuation of forests, and so deforestation has a number of deleterious impacts on livelihoods of forest inhabitants and on the local and global environment [8]. Biodiversity of forests is important for many reasons, including its role as a storehouse of genetic material that can be used to selectively breed plants and animals, its contribution to natural pest and disease control, and its ability to provide valuable pharmaceutical products. Forests also purify water by stabilizing soils and filtering contaminants. The quantity and quality of water flowing from forested watersheds are important for agriculture, hydropower, municipal water supplies, recreation, and habitat for fish and other wildlife species [9].

There are other benefits, such as sedimentation prevention and sustainable production of non-timber forest products, which are significant and of importance to local communities.

These benefits, however, are specific to limited geographic and economic environments. Other benefits, such as local climate regulation, are plausible and conceivably large, but subject to large scientific uncertainty. Still other supposed benefits, such as flood prevention in large watersheds, and maintenance of dry season water flow, are potential benefits.

Habitat in general and forests in particular, are internally quite heterogeneous. Any sizeable forest area is likely to exhibit substantial internal diversity in species density, soil types, slopes, and market access [10], while benefits such as soil and water conservation accrue to the society, the benefits of biodiversity and climate change are global in scope. Global interests generally call for greater preservation of forests than national interests [11]. Forestry activities provide many direct and indirect benefits to communities. The nature and significance of these benefits can vary greatly between countries, regions and even among communities. Forest benefits to mankind have been classified using various taxonomies, the most common being timber and non-timber forest products. Sometimes "wood" is substituted for timber. In this case, "wood benefits" include not only "timber" benefits but also other wood-based product such as firewood. The distinction is also often drawn between market (traded) and non-market values of forests, the latter including in particular ecological services of forests. There are a number of ways in which biodiversity and other non-timber benefits can be enhanced by management and harvesting systems. Sometimes these changes can be made at little cost to timber production activities, at other times the tradeoffs may be significant [12]. Forest ecosystems also provide habitat for some endangered species [9].

## 3. Current and Emerging Threats

Threats to forests are changing in part because the drivers of forest change are also changing. As habitat conversion and fragmentation increase, the forests become vulnerable to a relatively newly recognized threat: invasive species and pathogens. Species are disappearing at a profound rate in ecosystems [13]. Due to the high level of habitat fragmentation, forest restoration has become an essential component of all policy strategies aimed at the reduction of local and regional species extinctions, continued provision of ecosystem services, climate change adaptation, and promotion of human well-being [14].

There is a far more diverse range of threats to forests from landscape alterations, such as habitat fragmentation and selective logging, to far more insidious and poorly understood threats like forest fires, exotic pathogens, and growing synergisms among simultaneously, interacting threats [13]. On the other hand, some of the threats to

forests are only newly recognized whereas others are emerging as more complex than previously thought. Clearly the challenge is even bigger, tougher and more daunting than previously understood. The capacity of the rainforest to recycle water through evapotranspiration and thus generate some of its own rainfall [15] is also being impaired by hydrologic intensification resulting from climatic change.

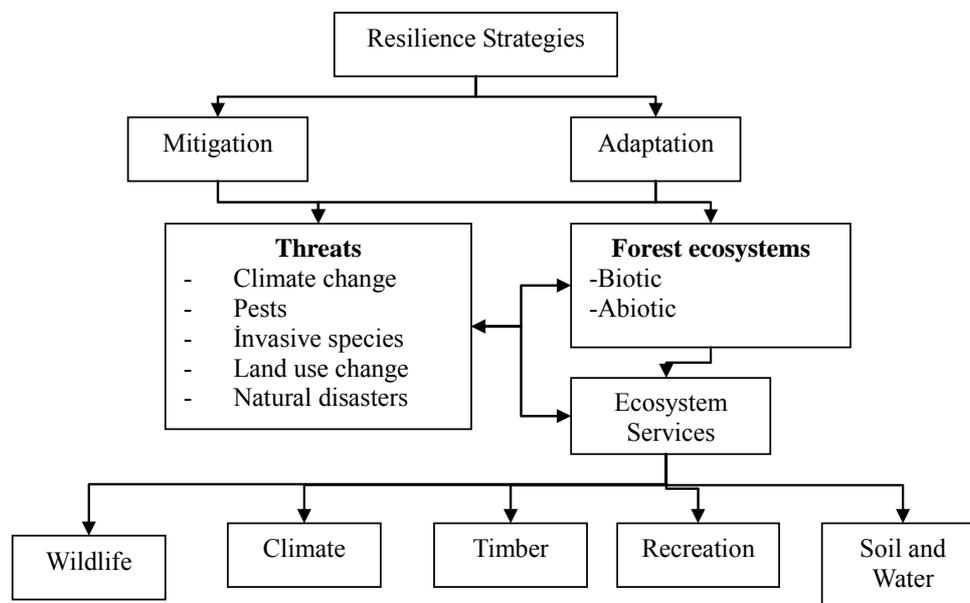
Natural disasters like fires can also severely erode forest biodiversity and ecosystem services [16]. Increasingly, the drivers of change in forests are not just local or regional but also global in scope. Rising atmospheric carbon dioxide levels, increasing temperatures, increasing storm events, and altered regional patterns of precipitation are just some of the possible consequences of global climatic change. In recent decades, basic changes in mature forests, such as increasing dynamism, biomass, and floristic composition, are evidently occurring-although it is difficult to identify unequivocally the specific drivers of such changes. Impacts of climate changes will surely become more significant in the future [13]. Clearing the land for food production and urbanization may eliminate wildlife habitat for some species and reduce genetic diversity. Such conversion of natural ecosystems causes the most concern when it takes place on a large scale or when it alters a rare ecosystem that provides globally and regionally valuable goods or services such as habitat for an endangered species [9].

There is a need for the development of management strategies that increase the resilience of forest ecosystems towards sustainability of forest ecosystem. For this, a systems-based approach that identifies properties of the

forests that are vital to adaptability and resilience of forests becomes important. For example, forest composition is one of criteria that define the ecosystem response to stressors. In this paper, we review emerging threats to forest systems and propose a systems-based, resilience framework to enable adaptation to these threats. We discuss each threat and propose resilience strategies for each threat that could be used to identify optimal mix of strategies that can be selected through the use of a systems-framework. In addition, the resilience strategies need to be carefully designed to match with local conditions of the forest and nature of ecological and economics systems associated with the forest ecosystem.

#### 4. Resilience Framework

A framework for resilience strategies for mitigation forest threats is presented in **Figure 1**. Resilience measures are primarily concentrated in adaptation, but forest sequestration and temperature regulation can be classified as mitigation types. Thus a resiliency framework need to include both adaptation and mitigation strategies to increase resiliency of the forest ecosystem. Forest ecosystem comprises of biotic and abiotic components that need to be considered in resiliency enhancement. An ecosystem-based strategy needs to balance biotic changes like plant diversity, habitat enhancement, and heterogeneity, while protecting soil and water quality. Enhancement of ecosystem services thus becomes a vital part of forest management. Emerging threats to forest need to consider increasing adaptability and resilience of forest ecosystem to these stressors.



**Figure 1. Resilience framework for forest ecosystem conservation.**

## 5. Threats and Impacts

### 5.1. Climate Change

Long-term climate change, which is a slow changing parameter, can bring changes in the dynamics of multiple variables, thereby affecting the entire constellation of forest. This could also enhance disturbance processes like fire, drought, introduced species, insect and disease outbreaks, hurricanes, windstorms, ice storms, and landslides [17].

Local, regional, and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent, and intensity of disturbances. Because trees can survive from decades to centuries and take years to become established, climate-change impacts are expressed in forests, in part, through alterations in the disturbance regime. Even if changes cannot always be predicted, it is important to consider ways in which impacts to forest systems can be mitigated under likely changes in disturbance regimes [17,18].

Climate influences the survival and spread of insects and pathogens directly, as well as the susceptibility of the forest ecosystems [19]. Changes in temperature and precipitation affect herbivore and pathogen survival, reproduction, dispersal, and distribution. Indirect consequences of disturbance from herbivores and pathogens include elimination of nesting trees for birds and have negative effects on mycorrhizal fungi [20,21]. Other indirect effects include the impacts of climate on competitors and natural enemies that regulate the abundance of potential pests and pathogens [19].

Forest-carbon dynamics (the rate of fluxes and the stock resulting from net carbon exchanges) are driven by the climatic inputs which govern the rates of photosynthesis and respiration/decay. Rates of photosynthesis scale with increasing water availability, so long as thermal and radiation regimes are sufficient to support plant growth [7]. Concentrations of atmospheric CO<sub>2</sub> have been rising for more than 150 years (IPCC 2007) largely as a result of fossil fuel burning [22]. In addition to reducing anthropogenic CO<sub>2</sub> emissions, land managers can assess the potential to increase forest carbon sequestration and storage as a mitigation strategy. In theory, improvements in ecosystem management should allow forests to sequester more CO<sub>2</sub> as the forest growth rate improves, and thus help to mitigate anthropogenic CO<sub>2</sub> emissions. Climate change may present a serious challenge to the resilience of forest ecosystems globally [7].

### 5.2. Invasive Species

There are about 400 of the 958 species in USA that are listed as threatened or endangered under the Endangered Species Act. These are considered to be at risk primarily

because of competition with or predation by non-indigenous species [23]. In other regions of the world, as many as 80% of the endangered species are threatened and at risk due to the pressures of nonnative species [24]. In the past 40 years, the rate of and risk associated with biotic invaders have increased enormously because of human population growth, rapid movement of people, and alteration of the environment. In addition, more goods and materials are being traded among nations than ever before, thereby creating opportunities for unintentional introductions [25,26]. Large numbers of people are now hazard-prone and this will inevitably lead to increased disaster losses [27].

The increasing global movement of people and products is also facilitating the movement of exotic species around the world. These species may be unintentionally introduced to new environments in shipments of food, household goods, wood and wood products, new and used tires, animal and plant products, containers, pallets, internal packaging materials and humans. In the absence of natural predators, competitors and pathogens, they exotic species can prosper in new environments and spread at the expense of native species, affecting entire ecosystems [28].

Biotic forest disturbance resulting from the propagation, growth, and spread of biological organisms depend on forest resources to complete their life cycle. These disturbances include a diverse array of native and exotic insects, diseases, and invasive plants. Biotic disturbance are endogenous, and thus have a different suite of interventions available to influence the probability of occurrence and the extent of damages [29].

A lack of natural controls, such as predators, or pathogens, or inadequate defenses in trees, can allow insects to spread. Climate change could contribute to an increase in the severity of future insect outbreaks. Rising temperatures may enable some insect species to develop faster and expand their ranges northward. Invasive plant species can displace important native vegetation because the invasive species often lack natural predators. Climate change could benefit invasive plants, since they are generally more tolerant to a wider range of environmental conditions than are native plants [30].

### 5.3. Pests

Invasive and aggressive plant and insect species may gain advantage over native species with future changes. Many forest pests are limited by winter freezes, and with increased temperatures these species can increase in number and very likely have a greater negative impact on woodlands. Destructive insects, such as bark beetles, will be better able to take advantage of forests stressed by more frequent drought. Certain invasive plant species are

expected to increase dramatically as their large range and tolerance of harsh conditions will allow them to rapidly move into new areas [31].

Disturbances can interact with one another, or with changes in temperature and precipitation, to increase risks to forests. For example, wildfire can make a forest more vulnerable to pests [30,32].

#### 5.4. Landuse and Rapid Exploitation

Land use change like urbanization and cropland pose a serious threat to forest land throughout the world. Land-use practices have played a role in changing the global carbon cycle and, possibly, the global climate: Since 1850, roughly 35% of anthropogenic CO<sub>2</sub> emissions resulted directly from land use changes, especially into forest conversions. Land-cover changes affect regional climates through changes in surface energy and water balance. Humans have also transformed the hydrologic cycle to provide freshwater for irrigation, industry, and domestic consumption. Furthermore, anthropogenic nutrient inputs to the biosphere from fertilizers and atmospheric pollutants now exceed natural sources and have widespread effects on water quality and coastal and freshwater ecosystems. Land use change has also caused declines in forest biodiversity through the loss, modification, and fragmentation of habitats; degradation of soil and water; and overexploitation of native species [33]. About half the world's forests have been converted to agriculture and other land uses; as have substantial areas of other carbon dense ecosystem types [7].

Plants and animals that are susceptible to fluctuating conditions will respond to environmental changes by adapting, moving, or declining. Species with high genetic variation will be better able to adapt to new conditions. Increasing temperatures will cause many species to shift ranges, generally moving north or up in elevation. However, in many cases land use changes will restrict the ability of plants and animals to move into suitable habitat. The species most likely to be negatively impacted by climate change will be highly specialized, habitat restricted species. The quantity of organic matter, nutrient cycling, and water availability in soils are expected to change in the future, which will lead to changes in plant productivity. Higher temperatures will lead to increased decomposition of organic matter in soils, which over time can lead to an increased risk of soils compaction if Best Management Practices aren't utilized during harvests [31]. Due to large-scale land use change and the built environment, species' ability to disperse to new habitats may be extremely limited in some areas and natural migration unable to keep pace with the shifting climate [34].

## 6. Natural Disasters

### 6.1. Hurricanes

Hurricanes disturb forests of the eastern and southern coastlines of the United States, as well as those of the Caribbean islands and the Atlantic coast of Central America. Ocean temperatures and regional climate events influence the tracks, size, frequency, and intensity of hurricanes [35,36]. Global warming may accelerate the hydrologic cycle by evaporating more water, transporting that water vapor to higher latitudes, and producing more intense and possibly more frequent storms [35-37]. However, other variations may override possible increases in hurricane frequency [38]. Changes in the global hydrologic cycle and temperature will influence hurricane formation, but it cannot yet be predicted the direction and magnitude of change. Sea-surface temperatures are expected to rise, with hotter temperatures expanding to higher latitudes. Most studies point to an increase in hurricane frequency [39]. However, even if frequency does not increase, it is likely that intensity and possibly duration of individual storms will increase because of the warming of the air and ocean, sources of energy for a hurricane [35-37]. The effects of hurricanes on vegetation include sudden and massive tree mortality, complex patterns of tree mortality (including delayed mortality), and altered patterns of forest regeneration [40,41]. These changes can lead to shifts in successional direction, higher rates of species turnover, and opportunities for species change in forests, which can in turn increase landscape heterogeneity, produce faster biomass and nutrient turnover, and result in lower aboveground biomass in mature vegetation [42]. Hurricanes can also result in buried vegetation and carbon sinks.

### 6.2. Floods

The effect of flooding on forest systems is an important issue. Evidence to date is partly inconclusive, and therefore new data sources and analyses provide an important opportunity to further our understanding [43].

According to Laurence (2007) natural forests do reduce the frequency and severity of floods in developing nations [44]. There are many factors besides rainfall, catchment size and land surface condition that can affect the generation of floods. Soils, geology, catchment and river morphology, and antecedent conditions (e.g. catchment wetness) all influence catchment hydrological processes. On the other hand, the difference in interception loss between forest and short vegetation (e.g. grass or crops) is typically in the order of 15% of rainfall over longer periods, but varies as a function of storm size, weather conditions and canopy characteristics. Increasing population pressure can also lead to increased settlement

in floodplains without adequate flood protection [45]. There are also links between population and the fraction of occurring floods that are recorded. Floods in sparsely populated areas (e.g. natural forests) are more likely to go unreported in media and official records [43].

## 7. Resilience Strategies

Miller *et al.* 2007 suggest that no single solution fits all future challenges, especially in the context of changing climates, and that the best strategy is to mix different approaches for different situations. Resources managers will be challenged to integrate adaptation strategies (actions that help ecosystems accommodate changes adaptively) and mitigation strategies (actions that enable ecosystems to reduce anthropogenic influences on global climate) into overall plans [43].

Forests that are healthy tend to be more resilient to climate change. Forest adaptation measures related to climate change are often aimed to reduce the impacts of current ecosystem stressors. These measures include a wide variety of activities that are tailored to reduce impacts occurring or anticipated to occur within a specific forest [47].

Diverse forests are more biologically productive and provide larger and more reliable carbon stocks, especially in old-age stable forest systems [7]. Hence, protecting and restoring biodiversity serves to maintain the resilience in forests, in time and space, and could enhance their capacity to reliably sequester and store carbon. Carbon sequestration is an ecosystem service that provides a vital contribution to climate change mitigation and this service can be enhanced by maintaining ecosystem resilience in space and time [7].

Due to the importance of biodiversity conservation in forestry, landscapes should possess a structurally complex matrix, and buffers around sensitive areas. Management should maintain a diversity of species within and across functional groups. Highly focused management actions may be required to maintain keystone species and threatened species, and to control invasive species [48].

In Canada's forests, the impacts of climate change related to insects and disease are beginning to be addressed and the knowledge gaps are large [34]. Development of more sophisticated modeling capacity will help, although lack of data on many pests and diseases is a constraint. In the absence of detailed data, application of the well-understood principles of Sustainable Forest Management will assist forest managers in maintaining forest ecosystem health and productivity to the extent possible [34].

Some important pests are expected to increase due to the direct effects of increased temperature on reproduction, and the increased susceptibility of host trees due to

other stresses, e.g. drought [49-51]. The long-term effect of insect outbreaks on forest management is difficult to predict, but recent research provides examples of tree mortality resulting from the interaction of insects, drought and fire in the southern margin of the boreal forest in the Prairie Provinces [49-52].

Resilience to climate change must become a mainstream consideration when preparing land use plans, reviewing urban planning proposals, or making decisions about future urban infrastructures and services [53].

The problem of land resources under stress has physical, social and political causes. At the national level, short-term political gains have often been made at the expense of long-term environmental damage. Decision-makers often face difficult decisions when trying to increase production to alleviate poverty and feed people and at the same time conserve resources to mitigate environmental degradation. Often decision-makers forfeit long-term sustainability for immediate needs. This also holds true for the subsistence level land users who have little choice but to seek immediate benefits for survival. Technology alone cannot be viewed as an answer. Frequently the technologies to manage such areas in a sustainable way are simply not available, or the land users do not have access to them due to lack of information or resources. However, a key factor is the role of human institutions and land use policies that must be adapted to face the challenge posed by these rapidly changing conditions [54]. There is a need for increased plant diversity in forest ecosystem to enhance resilience to natural disasters [7]. There is no single key to mitigate or avoid harm on forest the best strategy is to combine different approaches for different situations as shown in **Table 1**. All resilience strategies should be expected to be changed for different forest types (**Table 2**). Furthermore, it is important to distinguish between the proximate and underlying causes of forest loss. The proximate causes include unsustainable logging, slash and burn agriculture, the building of infrastructure such as dams and roads, pollution, fires, infestation, invasive species etc. Statements about proximate causes provide little insight into the issues which would have to be addressed by policy measures [6]. While resilience measures can focus on specific adaptation strategies, we recommend use of a multi-pronged approach that is based on the systems framework of resilience proposed as applied to specific forest ecosystems.

## 8. Conclusions

Forests are a critical part of sustainability of human and ecological systems. With multiple ecosystem services provided by forests, there are several emerging threats that need a renewed approach to forest management.

**Table 1. An approach to combine resilience strategies for threats to forests.**

Threats	Impacts	Resilience strategies
Climate change	Forests both influence and are influenced by climate change: they play an important role in the global carbon cycle, and their management or destruction could significantly affect the course of global warming in the 21st century [55].	Adaptation and mitigation [56].
Invasive species	In the absence of their natural predators, competitors and pathogens, they can prosper in new environments and spread at the expense of native species, affecting entire ecosystems [28].	Improvement of forest management, invasive management policies.
Pests	They are very likely have a greater negative impact on woodlands. Conversion of forest to agricultural land, forest degradation due to insect pest has impacts like overharvesting, overgrazing, fires and diseases [57].	Forest restoration, integrated pest control.
Landuse and rapid exploitation	Land-cover changes affect regional climates through changes in surface energy and water balance.	Forest management, land use policy.
Natural disasters	Threat to life and livelihood [58].	Prediction and management of natural hazard and human vulnerability [59].

**Table 2. Forest area by forest type.**

Tropical (thousands km <sup>2</sup> )										
World region	Freshwater Broadleaf (8)		Sclero-Phyllous dry forest	Needleleaf (9)	Mixed Needleleaf /broadleaf forest	Sparse Trees and parkland	Disturbed (6) Plantations (7) Total			Total Tropical and non-tropical
	Swamp forest									
Africa	-	3.8	18.1	-	28.5	0.0	-	-	50.3	5,683.1
SE Asia (insular)	-	-	-	-	-	-	-	-	-	1,468.4
SE & S Asia (continental)	1.7	70.0	16.3		33.0		41.8		162.8	1,526.0
Far East	-	296.5	49.1	361.9	261.7	419.2	-	65.5	1,453.8	1,456.0
Middle East	-	15.2	108.2	34.0	10.3	-	-	-	167.7	167.7
Russia	-	1,466.3	-	6,687.4	-	103.5	-	-	8,257.2	8,257.2
Europe	-	550.2	22.8	1,167.2	75.2	-	-	-	1,815.4	1,815.4
North America	121.7	1,275.5	225.0	4,102.8	1,233.6	1,488.3	-	-	8,447.0	8,454.0
Central America	-	-	48.5	-	164.4	-	-	-	212.9	890.1
South America	3.6	360.6	8.2	-	0.7	129.2	18.7	-	521.1	8,429.5
Caribbean	-	-	-	-	-	-	-	-	-	53.8
Oceania	-	56.4	203.3	11.2	-	431.0	-	-	701.9	1,493.2
<b>TOTAL (thousands km<sup>2</sup>)</b>	127.0	4,094.5	699.5	12,364.3	1,807.5	2,571.2	60.5	65.5	1,790.0	39,694.3
<b>TOTAL (millions hectares)</b>	12.7	409.4	70.0	1,236.4	180.7	257.1	6.1	6.5	2,179.0	3,969.4
<b>Percentage of World</b>	0.3%	10.3%	1.8%	31.1%	4.6%	6.5%	0.2%	0.2%	54.9%	100.0%

Non-tropical (thousands km <sup>2</sup> )										
World Region	Freshwater broadleaf (8)		Sclero-Phyllous dry forest	Needleleaf (9)	Mixed Needleleaf /Broadleaf forest	Sparse Trees and parkland	Disturbed (6) Plantations (7) Total			Total Tropical and non-tropical
	Swamp Forest									
Africa	-	3.8	18.1	-	28.5	0.0	-	-	50.3	5,683.1
SE Asia (insular)	-	-	-	-	-	-	-	-	-	1,468.4
SE & S Asia (continental)	1.7	70.0	16.3		33.0		41.8		162.8	1,526.0
Far East	-	296.5	49.1	361.9	261.7	419.2	-	65.5	1,453.8	1,456.0
Middle East	-	15.2	108.2	34.0	10.3	-	-	-	167.7	167.7
Russia	-	1,466.3	-	6,687.4	-	103.5	-	-	8,257.2	8,257.2
Europe	-	550.2	22.8	1,167.2	75.2	-	-	-	1,815.4	1,815.4
North America	121.7	1,275.5	225.0	4,102.8	1,233.6	1,488.3	-	-	8,447.0	8,454.0
Central America	-	-	48.5	-	164.4	-	-	-	212.9	890.1
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Caribbean	-	-	-	-	-	-	-	-	-	53.8
Oceania	-	56.4	203.3	11.2	-	431.0	-	-	701.9	1,493.2
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<b>Percentage of World</b>	0.3%	10.3%	1.8%	31.1%	4.6%	6.5%	0.2%	0.2%	54.9%	100.0%

Source: Secretariat of the Convention on Biological Diversity, "The Value of Forest Ecosystems", Montreal, SCBD (CBD Technical Series no. 4), 2001, p. 37 [6].

Enhancing the resilience of forests to handle emerging threats requires a mix of adaptation and mitigation strategies that follow a systems approach in management.

While each threat requires specific technologies and policies to enhance adaptation, a system-wide strategy that can enhance the synergy in approaches to arrive at multiple benefits can be advantageous. There is a need to use the resilience framework in a dynamic manner to develop adaptation strategies that vary over geographic space and time.

Resiliency research is still at its infancy and there is a need for further research through monitoring, assessment of human interactions, changes in adaptability over time, and nature of interaction between adaptation outcome and forest characteristics. There is a need for research into forest resilience at multiple scales.

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