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Chapter

Ecosystem Services in the Changing Climate: Calling Attention for the Conservation of Tropical and Subtropical Forests

Gul Zareen Ghafoor, Memuna Ghafoor Shahid, Maryam Ali and Naghmana Ghafoor

Abstract

Tropical and subtropical forests have diverse ecological functions but are most disturbed due to climatic changes. Peer-reviewed articles, books and reports were searched and downloaded to analyze the effect of climatic changes on tropical and subtropical forests and highlight the need for conservation efforts to ensure sustainable supply of ecosystem services. These forests store largest share (55%) of global terrestrial carbon pool. But the projected rise in temperature (4°C), CO₂ levels (495 ppm) and changes in precipitation regime by 2100 are expected to cause significant changes in ecosystem productivity and nutrient turnover rate making forests more vulnerable to climate change. High temperature with low rainfall reduces tree growth, increases soil carbon fluxes by accelerating rate of nutrient cycling, restricts the range of pollinators and increases pest infestation (*Phytophthora cinnamomi*) affecting ecosystem health and future food security. Increase in heat waves increase the incidence of wild fires and degrade ecosystem quality. Climate change also reduces the scenic beauty, ecotourism and associated economic and mental health benefits. Proactive measures must be taken to mitigate the likely causes of climate change and efforts should be taken to conserve the existing forest reserves to ensure sustainable supply of the ecosystem services.

Keywords: climate change, tropical forest, subtropical forest, ecosystem services, nutrient turnover, carbon stock

1. Introduction

Forests globally cover 4.06 billion hectares (31%) of land area and provide diverse ecosystem services mainly categorized as regulatory, provisioning, supporting and cultural services [1, 2]. These services have use (tangible) and non-use (in-tangible) values. The use values encompass a diverse array of benefits to the humankind in term of provision of food, timber, shelter and fuel-wood. The non-use benefits include
climate regulation, nutrient cycling, flood protection, oxygen production, and prevention of soil erosion, recreation, scenic beauty and spiritual services [3, 4]. All of these services are vital for the mankind and ecological communities to sustain on this planet but are under constant threat from changing climate [5].

The uncontrolled anthropogenic activities related to urban and industrial expansions, fossil fuel burning, deforestation, and land use land cover (LULC) changes have caused rise in atmospheric CO\(_2\) levels. Since the pre-industrial times (back in year 1800), 50% increase (280–412 ppm) in the CO\(_2\) concentration has been observed causing 0.85°C rise in global temperature [6, 7]. The CO\(_2\) concentration has risen with a growth rate of 5.1 GtC/yr during 2011–2020 [7]. The emissions are expected to reach the dangerous level of 495 ppm by the year 2100 and are projected to raise global temperature by 4°C [8–10]. This warming trend has already affected forest ecosystems globally and can further reduce the supply of ecosystem services [11, 12].

Geographically, tropical and subtropical forests are located at 23.5°N and 23.5°S latitude in the regions delimited by 18°C to –3°C isotherms according to the Koeppen Geiger climate classification. These forests are characterized by little variation in overall temperature and comparatively high rainfall. These forests cover parts of Asia, Africa, South America and Australia having distinguished features such as seasonal leaf fall, physiographic position, leaf size and canopy structure [13].

Among all the other forest types, the tropical and subtropical forests host most diverse array of tree species and also contribute significantly in carbon sequestration [14]. Out of 2.4 GtC/yr stored annually by global forests, about 55% of this is stored in tropical and subtropical forests while boreal and temperate forests store only 32% and 14% of it respectively [15]. Along with climate regulation, these ecosystems are also a source of livelihood for the local communities, provide food security and maintain ecological health. Yet these tropical and subtropical forests are at the forefront of changing climate due to their geographical location. The climate change impacts on the ecosystem services of the tropical and subtropical forests are considered a major threat in current century. The projected increase in temperature up to 4°C can cause significant changes and alternations in the ecosystem structure and the functions [8]. The different effects of climate change like increase in temperature, CO\(_2\) concentration and changes in rate of precipitation cause many negative impacts on the ecosystem services of the tropical and subtropical forests [16]. These climatic changes might cause tree species to shift their range towards poles and also affect rates of nutrient turnover [17, 18]. Therefore, there is a dire need to prioritize conservation and restoration efforts to protect the ecological functions of these ecosystems.

2. Methodology

This chapter was aimed at analyzing the effect of climatic changes on ecosystem services provided by the tropical and subtropical forests. The chapter has also been designed to highlight the conservation measures necessary to be taken to ensure sustainable supply of the ecosystem services. Therefore search of literature covered broadly two main issues; the effect of climate change on Ecosystem services of the tropical and subtropical forests and the conservation efforts to save the natural systems. Peer-reviewed journal articles, books and reports were collected from trusted websites and publishers. The key words used during the search were ‘ecosystem services, changing climate, conservation efforts, tropical and subtropical forests,
precipitation, warming, CO\textsubscript{2} extreme, provisioning, regulatory, supporting and cultural services. Boolean operators and truncations were used during the search of key words. Once the relevant literature was searched, it was thoroughly reviewed and analyzed and then presented in this chapter.

3. Results

3.1 Provisioning services and climatic extremes

Provisioning services are those services from which society gains benefits in terms of fulfilling their needs. These include provision of food, water, timber, fuel wood of direct domestic consumption. These services also include provision of plant based products such as fibers, medicines and raw materials extracted to prepare clothing materials as depicted in Figure 1. These services also render the use of bacteria, algae and fungi for their direct benefits or harvesting resources from these microscopic life forms. Among all of these, provision of food and fodder is the fundamental provisional service for the society [19, 20].

Tropical and subtropical forests have a major influence on the weather patterns, freshwater resources, biodiversity and food. These forests are considered the major sinks of the carbon yet face climatic changes which have caused reduction in their area at an alarming rate [21]. Deforestation and degradation has significantly affected these forests and the services they provide. These forests provide provisioning services like food, wood and timber to the millions of people however; decline of these forests has badly affected livelihood of forest dependent communities. Destruction of
these forests is also responsible for release of tons of CO$_2$ in the atmosphere leading to positive feedback to climate change [22].

3.1.1 Provision of water

Tropical and subtropical forests have major role on the rainfall patterns. The destruction of these forests results in the reduction in rate/frequency of precipitation which in turn affect quantity and supply of freshwater to the ecological and human systems [23]. Similarly rising temperature trends coupled with reduction in rainfall frequency and intensity can have profound effects on forested watershed. Water is used for many purposes like household consumption, power generation, and industrial purposes and for the different agricultural purposes etc. [24]. It is also seen that in different parts of the world the water is limited due to climate changes and rising demands of people [25]. Climate change in the future dry years is expected to induce shortage in the availability of surface water and ground water recharge. Climatic changes are also known for triggering wild fires due to heat waves, which may also lead to deposition of sediments and debris in water channels reducing the water holding capacity of reservoirs. During times of high rainfall, the reservoirs may over flow (producing flood events) and can cause damages to human and natural systems. The deposition of debris also affects reservoir water quality increasing treatment costs [26, 27].

3.1.2 Provision of food

Tropical and subtropical forests also link with the global food production both in the direct ways as food (goods) and in the indirect ways in the form of ecological services like pollination and pest control. It has been estimated that about 70% of the principal crops of the world are dependent on the pollinators which is more important for the valuable production of food, fruits and nuts [28]. Climatic changes are known for reducing food production as a result of drought, changes in temperature affecting length of growing season or other extreme events. These climatic changes also affect life cycle of pollinators. When these tropical pollinators decline, the poor farmers are at alarming risk of economic devastation because of their dependence on agriculture for their livelihoods [29, 30]. Besides the deforestation, increased temperature also badly affects the tropical crop production and nutrient quality. The growth and development of the cereal crops is badly affected with the increased temperature and unprecedented rainfall events. So the different regions of the world are facing food security issues due to the climate change [31].

3.1.3 Timber provision

Climatic changes have also been reported for affecting timber production. Climate changes increases the intensity and frequency of wild fire events, floods, storms and prevalence of pathogens affecting plant health. All of these factors contribute to degradation of forest ecosystems and increase in the tree mortality affecting sustainable timber production for the dependent communities [32]. Timber is among one of the important materials required during construction activities and is also a raw material for industries. Low quality timber is also used as a fuel source meeting energy demand for poor people. The decline in the timber production in tropical and subtropical forests has caused poor people to shift to expensive energy alternatives [33].
3.1.4 Medicine provision

Due to minor seasonal changes in temperature (av. 5°C round the year) tropical and subtropical forests host a diverse array of flora and fauna. When the tropical and subtropical forests decline or degrade, the habitat of different species is also affected. These different plant and animal species have the major role in the ecosystem structure and the functions [34]. Among these functions, an important role these species are playing is their medicinal value. The lack of formal health services and synthetic medicines in the developing tropical countries cause people to rely on herbal medications. Many of the present day medicines derive their active ingredients from these tropical/subtropical floral and faunal species. The market of ethno-medicine and traditional health care system is quite large in tropical Asia, Africa and Latin America. However, climate change and subsequent habitat loss is significantly affecting the medicinal value of these ecosystems [35, 36].

3.2 Supporting services and climatic changes

Supporting services are those services which help in supporting and sustaining life on this planet. These services provide the indirect benefits to the natural systems itself and to the society. These services include photosynthesis (primary production), soil formation, nutrient cycling, oxygen production, water cycling and maintaining genetic diversity as shown in Figure 1 [37]. Tropical and subtropical forests provide these supporting services playing an important role in sustaining life on this planet.

3.2.1 Nutrient cycling and soil formation

Nutrient cycling and soil formation are among the major functions of the ecosystem. Nutrient cycling is a step by step process in which the nutrients are mineralized, absorbed and stored/immobilized in the biomass, enter into the food chain via trophic levels and finally enter into the soil when organisms die or shed their waste products. Once in the soil, the matter decomposes and mineralized to become part of the cycle again. Phosphorus, nitrogen, sulfur, carbon and oxygen are the basic elements that are used in the biomass production [38]. Climate change affects the rate of nutrient cycling and the soil formation of tropical and subtropical forests in different ways [39]. Climatic warming is known for accelerating the pace of decomposition thus affecting rates of nutrient cycling and soil microbial community composition in the tropical and subtropical ecosystems [40]. A fast pace of nutrient cycling results in positive feedback to climate change due to increased soil respiration and decomposition emitting more CO₂ and N₂O (by product of nitrogen cycle). Climate warming has also been known for increasing the rate of production of root nodules accelerating nitrogen uptake, making nitrogen rich leaf litter and ultimately more N₂O emissions from decomposing litter [41].

Climate warming and increase in precipitation is known for causing reduction in litter residence time in soil due to accelerated decomposition rates. This means that warmer and wetter future will make soils deficient in its organic carbon fraction. Soil organic matter is an important indicator of soil health. The organic fractions help in the conditioning of soil, making soil aggregates to improve its structure for effective root penetration, infiltration and aeration. On the contrary, elevated CO₂ levels are reported for suppressing the rate of litter decomposition in the tropical and subtropical environment due to accumulation of recalcitrant fractions and low leaf nitrogen
level necessary for microbial decomposition processes [18]. The geographic location of tropical and subtropical forests make these areas to be naturally warm, while the projected rise in temperature and precipitation can have devastating effects on soil quality, nutrient dynamics and overall ecosystem productivity [40, 42].

3.2.2 Primary production

Biomass production (primary production) is one of the fundamental functions of the tropical and subtropical forests and is linked to other services such as erosion control (roots binding soil) and evapotranspiration rate affecting water cycle [43]. The ecosystem primary production is linked with the rate of photosynthesis. Climate change affects the rate of biomass production and the services they provide [44]. It affects the rate of the photosynthesis in different ways (either positive for some species or negative for others) so the biomass production or net primary productivity of these forests is altered [45]. Long term warming is estimated to cause increase in the rate of photosynthesis by 7–29% for six subtropical tree species [46]. While short term warming affects the rate of stomatal conductance and stomatal density, rate of photosynthesis and carbon accumulation (biomass production) in *Schima superba* in subtropical environment [12]. The stored biomass can be used for the different purposes like the production of food, fodder, biofuel and timber.

3.3 Regulating services and climate change

Regulatory ecosystem services are the benefits obtained from regulating ecological processes. Ecosystems regulate the natural environment in various ways such as by regulating climate or maintaining air quality through carbon sequestration (removing excess CO$_2$ from atmosphere), water purification, erosion control, flood protection, pollinator and pest cycles and regulating intensity and frequency of natural disasters as depicted in Figure 1. Regulatory services are linked to other ecosystem services like they affect the supply of provisioning and supporting services as well [47].

3.3.1 Climate regulation

This is a fundamental regulatory ecosystem service important for maintaining the quality of air and regulating local and global climate patterns. This service refers to the removal of harmful greenhouse gases (CO$_2$) and sequestering it in plant biomass through the process of photosynthesis. The global forests have fundamental role in maintaining climate whereas, the tropical and subtropical forests present their largest share (55%) in the supply of this service [15]. The role of forests in carbon storage and sequestration is becoming of fundamental importance as the pace of climate change is accelerating. Countries that are signatory to REDD+ (Reducing Emissions from Deforestation, Forest Degradation, conservation, enhancement and sustainable forest management) get monetary incentives by enhancing their forest carbon stock [48]. However, the rate of carbon sequestration is mainly defined by climatic factors which if disturbed, affect global climatic patterns along with delivery of linked ecosystem services. It has been estimated that the rising atmospheric CO$_2$ concentrations can have fertilizing effect on plant growth in the tropics which might enhance rate of carbon sequestration. But elevated CO$_2$ levels have been estimated for accelerating the metabolic activities of the soil microbial flora. This will accelerate the rate of decomposition of organic matter and thus will speed up the rate of carbon turnover. A high soil CO$_2$ efflux means positive feedback to climate
change [49, 50]. The rising CO$_2$ levels have been reported for altering leaf litter chemistry in terms of increased lignin concentration (recalcitrant fraction), high C/N ratio but with low leaf nitrogen level in the tropical and subtropical ecosystems [49].

Other climatic factors such as precipitation can also affect this service. Tropical and subtropical species have been reported for experiencing reduction in growth rate and production of roots with low biomass in response to drought stress and increase in soil carbon loss in areas with high rainfall [51, 52]. Similarly warming coupled with elevated CO$_2$ levels is also observed for increasing the rate of soil CO$_2$ efflux and evapotranspiration (affecting hydrological cycle) with overall reduction in plant growth rate and potential for carbon sequestration [53]. Inter-specific differences have also been observed for tropical and subtropical forests in response to climate warming. The subtropical evergreen broadleaved species have been documented for showing increase in overall growth and biomass carbon accumulation in response to projected climatic warming while the subtropical deciduous species have been reported for reduction in their regulatory ecosystem service [41].

3.3.2 Pollination, disease and pest regulation

The pollination, disease and pest regulation service has direct effect on ecological and human health and well being. This regulatory service also affects other provisioning services like food and fodder production important for human and livestock survival. Climate change can greatly influence the pollinator species. Reduction in the range and distribution of Colombian stingless bees (important for honey production) has been documented under various climate change scenarios. This means that reduction in pollinators and pollination due to climate change would result in food security issues in the tropics in future affecting agriculture productivity and rural livelihoods [54]. Similarly, increase in rainfall intensity and rising temperature in the subtropical regions has caused increase in the incidence of infestation of Phytophthora cinnamomi in the woody plants resulting in root rot, cankering and death of plant [55]. Warm temperature is also reported for increasing the incidence of Cylindrocladium quinquesepatum infection causing leaf blight in tropical and subtropical forests in Southeast Asia and Australia [56].

3.4 Cultural services and climatic changes

Cultural ecosystem services are the non-material benefits that people obtain from ecosystems such as education, recreation, spiritual experiences, social relations and aesthetic appreciation [57]. The array of cultural ecosystem services is depicted in Figure 1. These services contribute to the overall well being of the dependent communities in terms of provision of mental, physical and social health benefits and improve the cognitive ability of a person [58]. Climatic extremes have been documented for reducing the physical and mental health benefits derived from these forest ecosystems. Ecotourism/recreation is linked with economic growth of a country however, rising temperature is also responsible for reducing this cultural ecosystem service due to increased onset of climatic extreme events [43]. The increase in the frequency and intensity of climatic disasters such as floods, heat waves, droughts results in degradation of natural areas thereby reducing their scenic beauty and associated ecotourism and health benefits. These climatic extremes also lead to loss of job/rural livelihood affecting community’s physical, mental and socio-economic health [59].
4. Conservation of natural systems

Considering the wide ranging effects of climate change on regulatory, provisioning, supporting and cultural ecosystem services, there is a dire need to take proactive conservation measures to increase the resilience and resource base of the tropical and subtropical forests. There exist research gap highlighting the effect of individual climatic factors on each of the ecosystem services. Significant number of studies has been conducted on the effect of climatic changes on provisioning and regulatory services, nutrient cycling and primary production of the tropical and subtropical forests, but to the best of knowledge little is known for cultural services. Climate change is a gradual process and is linked with anthropogenic activities. The rising demand for energy supplies (coming mainly from fossil fuel resources), unintended land use land
cover changes, increase in the air pollution and un-sustainable harvesting of forest resources are all linked with rising global atmospheric CO$_2$ concentration and temperature. In the tropic and subtropics, parts of the region might experience drought while other might experience floods in future. Therefore, the forests are expected to behave in different manner when dryness or wetness couples with warm temperature and elevated CO$_2$. Restricting the use of fossil energy resources and shifting to sustainable and renewable energy resources might solve the problem to some extent. However, conservation efforts focusing on reforestation and afforestation of the areas combined with restoration of degraded ecosystems can help in increasing the area of the forests and thus supply of the services as depicted in Figure 2. Other measures such as promoting sustainable harvest and maintaining biodiversity and genetic resources might reduce vulnerability of the forests to changing climate. The communities should be banned from removing wood and permission should be granted for the collection of fallen deadwood only to meet the fuel wood need of the rural poor. There is generally a lack of forest conservation regulations and community involvement in the management of tropical and subtropical resources. Effective implementation of forest management practices, stakeholder involvement along with enforcement of laws prohibiting un-sustainable extraction of forest resources might help conserving existing resources as shown in Figure 2.

5. Conclusion

Tropical and subtropical forests host a diverse array of species and play a significant role in delivery of ecosystem services. These forests are essential for ecological health and rural well being. The geographic location of these forests makes them more vulnerable to the impacts of changing climate. The projected rise in global temperature, changes in precipitation regime and elevated levels of CO$_2$ will affect the supply of ecosystem services which might cause devastating effects on ecological and human systems. However, forest conservation and restoration efforts combined with reduction in greenhouse gas emission sources, community involvement and strengthening the relevant local institutions can protect the natural resource base of tropical and subtropical regions. Further research is need of the hour to investigate role of each of the climatic variable on individual ecosystem services to fill data gaps.

Conflict of interest

The authors declare no conflict of interest.
Author details

Gul Zareen Ghafoor¹, Memuna Ghafoor Shahid², Maryam Ali³ and Naghmana Ghafoor⁴

1 Sustainable Development Study Centre, Government College University Lahore, Pakistan

2 Department of Botany, Government College University Lahore, Pakistan

3 Department of Economics, Lahore College for Women University Lahore, Pakistan

*Address all correspondence to: zareen.sdsc@gcu.edu.pk

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