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Chapter 2
Effect of Climate Change on Tropical Dry Forests

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ABSTRACT

Around 1.6 billion people in the world are directly dependent on forests for food, fodder, fuel, shelter, and livelihood, out of which 60 million are entirely dependent on forests. Forests silently provide us with ecosystem services such as climate regulation, carbon sequestration, harbouring biodiversity, synchronizing nutrient cycling, and many more. Tropical Dry Forests (TDF's) occupy around 42% of total forest area of the tropics and subtropics and facilitate sustenance of world's marginalized populations. Change in vegetation composition and distribution, deflected succession, carbon sequestration potential, nutrient cycling and symbiotic associations would affect TDF at ecosystem level. At species level, climate change will impact photosynthesis, phenology, physiognomy, seed germination, and temperature-sensitive physiological processes. In order to mitigate the effects of climate change, specific mitigation and adaptation strategies are required for TDF that need to be designed with concerted efforts from scientists, policy makers and local stakeholders.

INTRODUCTION

Forests are complex ecosystems that have a delicate balance of biotic and abiotic components that interact, influence, modify and adapt to each other. The term forest is a very widely used but an ill-defined term and globally there are around 800 ways in which forests have been defined (Lund, 2012). The Food and Agricultural Organization (FAO) defines forest as a 'land spanning more than 0.5 ha with trees higher than 5m and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*' (FAO, 2010). According to the Intergovernmental Panel on Climate Change (IPCC) forest is defined as vegetation type that is dominated by trees, and is defined in different parts of the world according to the variation in biogeophysical conditions, social structure and economics of the region (IPCC, 2014). Of the many parameters used to define forests such as type of vegetation, physiognomy, species composition, canopy cover is considered to be an important parameter. The way a country defines its forests largely

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depends upon the vegetation type, physiognomy, forest structure, ownership of land, and economic use. In Australia, the canopy cover of typical forest should be greater than 20% of the total area, whereas in South Africa the value should be greater than 60% (Reddy et al., 2013). In India, the Forest Survey of India (FSI) defines forest as 'all lands more than one hectare in area, with a tree canopy density of >10%, irrespective of ownership and legal status' (FSI, 2011). This means that regardless of the nature of the tree cover, whether it is natural or planted, or the trees species are alien or native, any area having a minimum tree cover density of 10% is a forest. Based upon canopy density, forests in India have further been classified into five classes namely; Very Dense Forests, moderately dense forests, Open forests, Scrub and Non-forest (ISFR, 2017). Classification of forests has received much attention in the past and there have been several classification systems based upon climate, vegetation type, physiognomy and floristics. The system of life zones was the first forest classification system based on climate (Holdridge, 1947). Mueller-Dombois & Ellenberg (1974) proposed a classification system that laid emphasis on physiognomy of vegetation. Westhoff & van der Maarel (1978) integrated floristics and physiognomy to classify forests. Champion & Seth (1968) recognized four major climatic zones in India that harbours 16 major forest types comprising 221 minor types. On the basis of species associations and bioclimate, Gadgil Meher-Homji (1986) defined 42 forest types in India. Recently, Reddy et al. (2015) used IRS resourcesat-2 advanced wide field sensor to classify forest and scrub types. Seventeen percent of the global standing tropical forests are represented by tropical dry forests (UNEP, 2011). Irrespective of their type, forests across the world are under threat due to global climate change (Deb et al., 2018).

CLIMATE CHANGE

Climate change is one of the most serious environmental threats faced by the world today. It was recognized as a significant global environmental challenge a couple of decades back. International efforts to address this issue began with the establishment of the Intergovernmental Panel on Climate Change (IPCC) by the World Meteorological Organisation (WMO) and United Nations Environment Programme (UNEP) in 1988. IPCC defines climate change as a 'change in climate over time, whether due to natural variation or due to human induced activity' (IPCC, 2001). This definition differs from that of the United Nations Framework Convention on Climate Change (UNFCCC), which refers to climate change as "change in climate attributed only to anthropogenic activities which is in addition to the natural climatic variability observed over comparable time periods" (UNFCCC, 1992). UNFCCC was adopted in 1992, with an objective of stabilizing the concentration of greenhouse gases (GHG) in the atmosphere.

Factors that cause or contribute to climate change are known as 'climate forcings' that can be either natural or anthropogenic. Natural factors include volcanic eruptions, alteration in sun's intensity, and very slow changes in the oceanic circulation or land surface. Anthropogenic activities are fossil fuel combustion, industrial activities, emissions from agricultural systems and waste decomposition. In the fifth assessment report the IPCC has stated that anthropogenic climate change is very much real and is bound to have widespread impacts on natural systems. The report also says that each of the last three decades have been successively warmer than any preceding decade since 1850, and the period from 1983 to 2012 has been warmest 30-year period in the last 1400 years in the northern hemisphere. Rise in the global mean surface temperature may reach up to 4.8^{o}Cby the end of the 21st century, whereas maximum increase is predicted in the Polar Regions (IPCC, 2014). In addition to rise in temperature and disturbed precipitation patterns, global climate change will also increase the frequency of extreme events such as

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droughts, cyclones, storms and hurricanes. Correspondingly rise in the severity of extreme rainfall and heat waves is also predicted. As a result, natural ecosystems including forests will be adversely influenced and may become more vulnerable.

Forests and climate are closely coupled and any alteration in one may have serious implications on the other. They influence each other and share a symbiotic relationship in which climate influences the type of vegetation and distribution of forests and forests in turn act as natural climate regulators (IUCN, 2017). The IPCC has projected that forests across the globe will be severely impacted due to climate and non-climate stressors that may lead to forest die-back, loss of biodiversity and compromised ecological benefits (IPCC, 2014). In fact deforestation is one of the key drivers of climate change as it reduces carbon uptake potential of an ecosystem. Forests provide a plethora of goods and services to mankind. Ecosystem services provided by forests include carbon sequestration, regulation of nutrient and water cycles, prevention of soil erosion and harbouring biodiversity. However, change in land use pattern due to urbanization compounded by overexploitation has adversely affected forests around the world.

EFFECT OF CLIMATE CHANGE ON FORESTS

Forests across the world have been a victim of human greed and overexploitation. According to estimates, forests covered around 45% of the earth around 10,000 years ago, and due to ruthless anthropogenic interferences they have been reduced to 31% in 2010 (FAO, 2010). FAO's Global Forest Resources Assessment (FRA) reports that we are continuously losing our forests and in the period between 1990 and 2015 world's forested area has declined from 31.6% to 30.6% (FAO, 2018).The rate of deforestation is skewed in the world and countries that are heavily dependent on forest show higher rate of deforestation. Developing countries of Latin America, sub-Saharan Africa and Southeast Asia have reported maximum loss of forest cover primarily due to conversion into agricultural farms. The threats to our forests will be augmented by climate change and all forests will not be able to adapt to the changing climate. It is projected that global environmental change may result in shifting of ecosystems and extinction of some species, particularly those who will not be able to adapt. The most vulnerable would be polar ecosystems and coral reefs.

There is an increasing consensus that increased incidents of floods, drought, storms and heatwaves have a link to climate change (Thomas & Lopez, 2015).It is predicted that the incidents as well as the intensity of extreme climate events and natural disasters will intensify in future climatic scenarios (IPCC, 2014). It is important to point out that these issues also have economic ramifications as in many parts of the world people are heavily dependent on forests. This would have adverse impacts on environment, ecosystems and also the socioeconomic life of the communities that are dependent on forests for their sustenance and livelihood. Between 1996 and 2015 more than 800 million hectares of forested land has been affected due to climate related disasters (FAO, 2015a). Natural disasters have serious economic implications and in the decade spanning 2003-2013, 26 such events lead to loss of 737 million USD (FAO, 2015b).

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EFFECT OF CLIMATE CHANGE ON TROPICAL DRY FORESTS

The tropical dry forests are one of the important biomes of the world and comprise slightly less than half of the global tropical and subtropical forests (Murphy & Lugo, 1986). They provide ecosystem services such watershed protection, flood control, maintaining soil fertility and regulate climate (Maass et al., 2005). According to the Food and Agricultural Organization tropical dry forests are defined as those experiencing a tropical climate, with summer rains, a dry period of 5 to 8 months and annual rainfall ranging from 500 to 1500 mm. These are primarily found in Africa, South America and Asia and are particularly concentrated in parts of Southeast Asia, northern Australia, Pacific region, Central America and the Caribbean (FAO 2001, 18). They exist in regions that experience mean annual temperature of 25°C and annual precipitation between 700 to 2,000 mm. Due to such climatic conditions 50% of the plant species are seasonally deciduous (Sanchez-Azofeifa et al., 2005). According to Pennington et al. (2006), the ecological definition of TDFs includes savannas, riparian forests, coastlines and mangroves among the associated vegetation types. Vegetation in these forests varies from tall, closed canopy trees to short scrub vegetation that does not form a closed canopy, particularly in areas that receive less rainfall (Pennington et al., 2000). The predominant vegetation include deciduous trees that reach up to a height of 30 m. Nine major life forms are represented in TDFs which include: evergreen woody plants, deciduous woody plants (40% of the woody species), sclerophyllous woody plants, succulent woody plants (including cacti), herbs, rosettes, lianas, CAM epiphytes and hemiparasites (Medina, 1995). Dense and entangled undergrowth is also commonly observed in these forests as there is optimal light penetration. Species such as cacti, bromeliads are abundant as they are resistant to drought. TDFs may occur in a variety of structure that may range from a tall, closed canopy forest to short scrub vegetation. These forest experiences seasonal drought stress and that makes it different from moist forest (Murphy & Lugo, 1986). Lack of forest fires and seasonal drought stress further make TDFs a unique biome markedly different from savannas or moist forests.

The TDFs share a close association with human culture and economic development particularly in the neotropical region (Trejo & Dirzo, 2000; Fajardo et al., 2005). They provide several advantages for agriculture by influencing pedogenesis, improving soil fertility and supporting short-cycled crop plants. In a review on tropical dry forests of the neotropics it has been reported that globally these forests may facilitate sequestration of up to 22 Pg of carbon as above ground biomass. Additionally, they also help in conservation of freshwater sources and support biodiversity by harbouring endemic species (Portillo-Quintero et al., 2015). It is also known that the dry climate limits the propagation of pathogens transmitted by mosquitoes (Ewel, 1999; Murphy & Lugo, 1986; Fajardo et al., 2005).In addition to providing several ecosystem services, tropical dry deciduous forests also provide source of livelihood. It supports some of the world's poorest people (Cunningham et al., 2008; Waeber et al., 2012).Their trees are important source of firewood, medicinally important compounds, and also harbour fauna. The goods and services provided by these forests are different from other forest types and hence their conservation and management strategies need to be different (Gumbo & Chidumayo, 2010). Despite their high economic and social significance, dry forests haven't received much attention and are among the most threatened and least understood forest ecosystems (Miles et al., 2006; Portillo-Quintero & Sanchez-Azofeifa, 2010). Lack of concern and scientific studies have put these forests at high risks than their humid counterparts (Aide et al., 2012).

There is lot of regional imbalance on the studies of TDFs. While there are several reports of analyses of effect of climate change on dry forests in neotropics, there are few reports for the same from Asia

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and Africa (Walker & Desanker, 2004; Glenday, 2008; Williams & Aquino, 2010). In Asia, there have been reports on dry forests of Thailand. However, the focus has been on structure and composition of the forests without any emphasis on climate change (Bunyavejchewin, 1983; Setalaphruk & Price, 2007). Asian dry forests that include dry forests of Indochina as well as those of Central India are not particularly well studied, despite being regionally extensive (Blackie et al. 2014). Up to 30% of forests in mainland Southeast Asia and 60% of Indian forests are classified as dry forest (Waeber et al., 2012). In Asia the major dry forest type found are deciduous Dipterocarp forests, mixed deciduous forests and dry evergreen forests (Wohlfart et al., 2014). Although the FAO launched an Asian Dry Forests Initiative, as compared to those in the neotropics, the dry forests of Asia have received lesser attention. The trend is worrisome because Asian countries are more prone to the deforestation and have less adapting capacity and increasing population pressure (Bawa & Dayanandan, 1997). In India, excessive deforestation has resulted in patched distribution of TDF wherein they appear as mosaics of open canopied, and closed canopied in some undisturbed regions (Raghubanshi & Tripathi, 2009). TDF are also found in the Pacific region and according to Gillespie et al. (2012) the expanse of dry forests in some Pacific islands has been reduced to less than 10% of their original area due to anthropogenic activities and predominance of invasive species.

There are three major features of climate change that directly influence growth and behaviour of TDF: Higher global atmospheric CO_2 concentration, rise in global mean temperature and erratic rainfall pattern. At species level, increasing atmospheric CO_2 and temperature influence key physiological processes such as photosynthesis, respiration, seed germination and other temperature sensitive physiological processes. Indirectly these process influence carbon sequestration potential, soil organic carbon, nutrient cycling and symbiotic associations. At community and ecosystem levels, change in climate parameters alters phenology, succession and plant-animal interactions (Figure 1).

Shift in Vegetation

Global warming and alteration in precipitation patterns may lead to shifting of major ecosystems and biomes across the world. Increase in aridity has resulted in retreating of some tropical and temperate forests, while the savannas have expanded. The IPCC predicts that climate change would lead to boreal tipping point that would lead to thawing of permafrost resulting in threatening arctic ecosystems. Also it would result in increased shrub vegetation in the tundra and rise in incidents of forest fires in the boreal forests (IPCC, 2014).Studies have also indicated that terrestrial ecosystems in the alpine regions may shift towards the poles (Haywood et al., 2016). The shift is not restricted to latitude alone and Settele et al. (2014) have reported that vegetation and ecosystems show significant altitudinal shifts. Scientists have been using various models to predict the behaviour of vegetation to changing climate parameters. Analyses have been done to predict and project alteration in ecosystems by using models that use multiple parameters (Warszawski et al., 2013, 2014; Frieler et al., 2017). Analysing shifting patterns in the northern hemisphere, Thuiller (2007) concluded that terrestrial plants have shifted northwards on an average of 6.1 km per decade. Also, they have shown an advancement of phenoevents by 2.3 to 5.1 days in the last 50 years. In India, Telwala et al. (2013) have observed a climate change induced shift in the plants of TDFs in the Sikkim. Bates et al. (2008), have predicted a 5–15% reduction in soil moisture availability and runoff by the late twenty-first century across tropical Latin America, and studies have also reported the alteration in the length of the dry and growing season during the past decades (Sanchez- Azofeifa et al., 2013).

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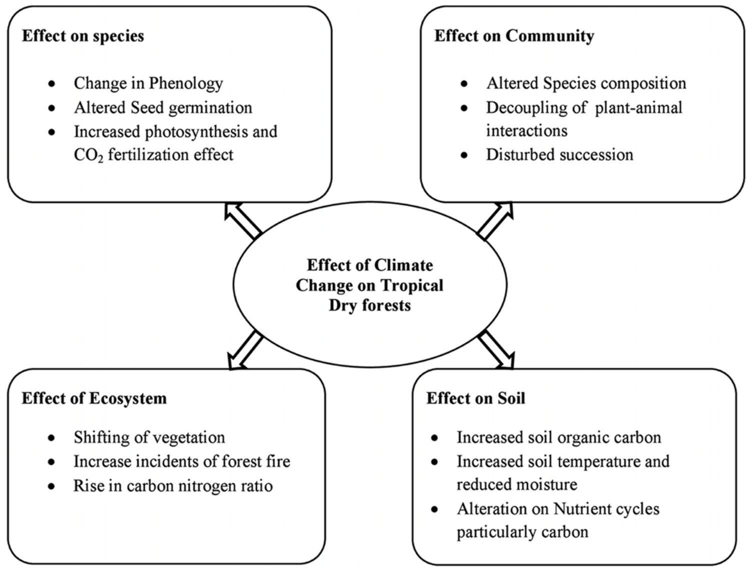
Figure 1. Diagrammatic representation of effect of climate change on tropical dry forests



Distribution of Forests

Miles et al. (2006) compared global distribution maps of TDF and concluded that climate change is a significant factor that affects the TDF of Americas in particular. In Africa TDF are under threat due to habitat fragmentation and fire. Conversion of forest land into agricultural fields and increasing population pressure is a matter of concern for Eurasian TDF. Using dynamic global vegetation model, Meir & Pennington (2011) predicted the effect of climate change on neotropical dry forests, and concluded that warming rates for TDF regions are consistent with, or slightly above, the global predicted means of approximately 2–4^{o}C warming by 2100. In a review of impact of climate change on seasonally dry tropical forests Allen et al. (2017) concluded that rise in frequency and severity of droughts will significantly affect distribution of species and other ecosystem processes. They concluded that temperature variation has serious implications for both above ground as well below ground processes of the forests. Mehta et al. (2008) reported that poor soil conditions may lead to a conversion of tropical dry forests into scrub vegetation. After analysing the TDF of southern India they concluded that distribution of trees, their phenology, physiology and growth of dry tropical forests is affected due to change in rainfall patterns.

Phenology

Phenology, the science of recurring events in nature, is a sensitive indicator of global climate change. It usually refers to the annual course of developmental events. Plant phenology is one of the most responsive and easily observable traits in nature that changes in response to any change in climate. Alteration in plant developmental events brought about by the current anthropogenic global climate change may have major impacts on plant productivity, competition among plant species and their interaction with other organism. Phenology also plays a crucial role in maintaining the carbon balance of terrestrial ecosystems

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(Keeling et al., 1996) and in determining shifts in agricultural zones (Fischer et al., 2002). Any changes in the timing of flowering may alter processes at species, community and ecosystem levels (Springer & Ward, 2007). At the community level, differential effects of elevated CO_2 on flowering time may lead to change in community composition by altering interaction among species. Alteration in flowering time may have different implications for different plant groups. Advancement or delay in flowering time in annual plants would lead to either shortening or lengthening of the plant cycle, which in turn may disrupt the sowing of the subsequent crop. In perennials, altered flowering time may influence the resource availability for seed production during specific reproductive events (Stearns, 1992). TDFs are composed of species that show different degree of adaptation to seasonal droughts. Events such as leaf fall, leaf emergence, and extend of deciduousness is well synchronized with periodicity of rainfall and availability of soil moisture. Any alteration in the precipitation and heat periods would significantly affect process such as duration of deciduousness, bud break and flowering time of tree species in Indian forests (Singh & Kushwaha, 2005). In a review of TDF of the Caribbean region by Nelson et al. (2018) observed that change in precipitation and temperature may lead to change in species composition, growth and reproductive capacity of trees. Khayani et al. (2016) have projected that in Puerto Rico climate change may lead to shift in the forest type from subtropical dry forest to dry forest by 2099. It is important to mention that any change in phenology of dominant tree species of forests may have rippling effects on several other plant and animal species that are dependent on them. Also phenological change in many species simultaneously may change the course of evolution of the forest as an entity. It will alter succession and in turn will have serious consequences for ecosystem functioning. What is worrisome is that there are no extensive studies on understanding climate change impacts of phenology of TDF species.

Carbon Dynamics

Forests are a crucial and critical link in the global carbon cycle. Irrespective of the forest types all forests are involved in cycling of carbon and its conversion from inorganic form i.e. atmospheric CO_2 to organic form via the process of photosynthesis. They also act as carbon sinks and make carbon a part of biological cycle. Forests are integral part of the carbon cycle that maintains delicate balance between inorganic and organic forms of carbon in atmosphere, biosphere, hydrosphere and lithosphere. Needless to say, that depletion of forests leads to disruption of an important link in the carbon cycle. Alteration in Carbon sequestration potential of forests may lead to the loss in carbon trapped in biosphere that may in turn accelerate climate change. Forests are the largest storehouses of carbon after oceans and can absorb and store carbon in their biomass, soils and products, equivalent to about one tenth of carbon emissions projected for the first half of this century. At the same time, deforestation and land-use changes account for 17 per cent of human-generated carbon dioxide emissions. Global climate change may have direct effects on terrestrial carbon reserves, and may indirectly lead to increased incidents of forest fires and pest and pathogen attacks. The 21st century may witness increased trees mortality and forest dieback (IPCC, 2014). Such events may have adverse impact on carbon storage, biodiversity and wood production. According to the International Union of Forest Research organization in predicted climate change scenario, the forests of the world may end up losing all their carbon regulating services and terrestrial ecosystems may start to behave as source of carbon rather than sinks (Seppala et al., 2009). Any change in land use leads to altered carbon: nitrogen ratio in different soil fractions. In tropics, change in land use results in releasing of stored carbon thereby increasing green house gases emissions (Don et al., 2011). In Mexican dry forests, it has been observed that slower turnover of carbon and other nutrient

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contribute to the negative relationship between soil carbon sequestration and mean annual precipitation across (Campo & Merino, 2016). In an analysis of relationship between soil organic carbon and aridity Delgado-Baquerizo et al. (2013), suggested that extremely dry conditions may adversely affect ecosystem carbon storage as the carbon inputs from plant productivity, erosion and fire decrease. Boisvenue & Running (2006) analyzed the effects of climate change on forest productivity and concluded that forest productivity will increase in the absence of water stress. On the contrary Aber et al. (2001) projected that in the US alone about 20% of forests may experience loss of carbon in case temperature and precipitation were to increase. Holm et al. (2017) observed the effect of hurricanes on Net Primary Productivity (NPP) in the Carribean and concluded that increased incidents of hurricanes will increase the NPP of dry forests in the Carribean. Using HadRM3 model Chaturvedi et al. (2011) projected that in India, the NPP will increase by 68.8% and the soil organic carbon may show a rise by 37.5%.The rise is NPP will be higher in northwest India due to higher temperature and wetter climate. The study also reported that NPP may marginally increase or may even decrease by up to 12% in central and western India which is dominated by dry forests. Therefore it may be concluded that how forests respond to changing climate will vary locally within country. Therefore, further long-term studies are warranted to generate a comprehensive understanding towards the impacts of global climate change on TDFs.

Symbiotic Associations

Among the below ground processes, plant microbe interaction is very crucial for plant and soil health. The below ground dynamics facilitate mineral nutrition for plants by conversion of bio-unavailable form of minerals to bio-available forms by microbes. Even though not much attention has been paid to below ground processes such as rhizosphere dynamics, symbiotic associations and nutrient cycling, all these processes may change due to rise in temperature in future climate scenarios. Free living and symbiotic soil microorganisms help in inter-conversion of nitrogen, phosphorous and sulphur. The symbiotic association between N fixing legumes and roots of higher plants is sensitive to abiotic stresses such as high temperature, drought and salinity. Scarcity of water has limiting effect on initiation, growth and function of roots nodules (Serraj et al., 1999) as well as on growth and survival of rhizobia (Hungria & Vargas, 2000). In TDFs the event of nodulation fluctuates with season (Gonzalez-ruis et al., 2008, Gei & Powers, 2015). Any alteration in the season may affect the phenology of nodulation or may even induce premature senescence. These changes are particularly undesirable for seedlings. Therefore, it may be concluded that scarcity of water and increased temperature due to climate change may directly influence nitrogen fixation by symbiotic N fixers. However, for better understanding of carbon nitrogen dynamics under future climate more focussed and targeted studies are required that essentially should be region specific.

Community Dynamics

Analysis of data from experimental analysis as well as modelling studies suggest that under severe drought or increased rainfall events the structure and function of seasonally dry forests would change (Chadwick et al., 2015; Feng et al., 2013; Greve et al., 2014). Structural and functional changes in forests further influence biodiversity and results in shifts in species range (Enquist, 2002). Disturbed forests would also have diminished capacities to provide ecosystem services. In fact, it would take several years to conclusively say how dry forests would behave in changing climatic scenario. TDF take longer time to

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regenerate from intense or prolonged droughts (Angeler & Allen, 2016) as compared to wetter tropical forests. Meta-analysis of effects of drought on temperate zone revealed that dry ecosystems took the longest to re-establish normal growth after being exposed to extreme drought (Anderegg et al., 2015). Study on long term effects on community dynamics of TDF of Costa Rica by Enquist & Enquist (2011) reported that extended drought periods lead to reduction in number of small sized tree. On the contrary Suresh et al. (2010) reported that trees with large girth were more resistant to the effects of annual climatic fluctuations. Abiotic factors such as light, water and nutrient composition of soil has significant influence on growth and survival of seedlings in TDFs (Tripathi et al., 2016). Bhadouria et al., 2016 analyzed the interactive effects of various abiotic factors on growth, survival and regeneration of tree species of TDFs. However more elaborate and long-term simulation studies are required to conclusively say how climate change affects TDF. There are many gaps in existing knowledge that needs to be filled up by conducting well-replicated drought simulations or experiments, distributed across the range of dry forest climatic variation and biogeography.

Incidents of drought and heat under projected climate change will results in increased mortality of tree species that in turn alters species diversity and composition (Allen et al. 2010). Moist forests are well equipped to withstand scarcity of water however TDFs have less resilience towards water stress. Therefore, species mortality through water deficiency was found to occur more in the tropical dry forests, and it severely affected trees of small diameter (Suresh et al., 2010). It has been observed that due to lower infiltration and evapotranspiration there is a shift in the species composition of TDF (Krishnaswamy et al., 2013). TDFs play a significant role in regulating the hydrological cycle. In a review of studies conducted on tropical dry forests in the neotropics Portillo- Quintero et al. (2015) have pointed out that climate change and change in land use may have serious implications on the natural and socioeconomic structures in the region. Water scarcity and droughts would have adverse impacts on the structure; composition and functioning of TDFs. Change in temperature and rainfall significantly influence seed health, vigour, and seedling germination. There have been studies analysing the effect of variation in rainfall on seed rain dynamics of dry forests (Martinez-Garza et al., 2013; Meave et al., 2012). Increased duration of dry periods may even lead to delayed or unsuccessful seed germination.

INDIAN SCENARIO

India is a mega biodiverse country and geographically it lies at connexion of three diverse biogeographic realms, the Indo-malayan, Eurasian and Afro-tropical (Reddy et al., 2015). We are the seventh largest country of the world and occupy an area of 32,87,263 km^2 and are bestowed upon a rich flora and fauna due to diverse climatic, topographic and geographic conditions. According to the India State forest report (2017) 21.54% of the total geographical area that is around 7.08 lakh square km is covered by forests. Highest forest cover is found in the state of Madhya Pradesh followed by Arunachal Pradesh. As a country we have added 6,778 km^2. of forests since 2015 (ISFR, 2017). Based on multi-season IRS Resourcesat-2 Advanced Wide field Sensor, Reddy et al. (2015) developed a classification system for Indian Forests and concluded that tropical dry deciduous and tropical moist deciduous forests are the predominant and occupy 34.8% and 7.72% of the total forest area. Tropical Dry deciduous forests are found in Western Himalayas, Gangetic plains and semiarid regions of Deccan peninsula. Dominant tree species are *Anogeissus latifolia*, *A. penduala*, *Albizia procera*, *Anthocephalus chinensis*, *Diospyros melanoxylon* (Reddy et al., 2015). According to Ravindranath & Sukumar (1998), rise in temperature

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and reduced precipitation in central India may result in reduced soil moisture that would eventually lead to increased seedling mortality. They also predicted that the moist type of forests may change to dry type in central India. Regional studies have shown that the dry deciduous forests of Western Ghats may decline in projected climate change scenario.

TDFs of peninsular India are divided into three types, namely: teak, Sal and miscellaneous types. The area is dominated by *Tectona grandis* (teak) followed by *Shorea robusta* (sal). In a study of dynamics of dry forest of South India, Schmerbeck (2011) concluded that forest fires are dominant anthropogenic factor in dry deciduous forests which are considered the most vulnerable ecosystems. In fact, the study also reported that lack of research and proper management has even converted some of the tropical dry forests into savanna and grasslands.

General Circulation Models were used initially to analyse the effect of climate change on Indian Forests (Ravindranath & Sukumar, 1998; Ravidranath et al., 1997). Using Regional Climate model of the Hadley centre (HadRM3) Chaturvedi et al. (2011) projected that on an average 39% of forest grids analysed would change under climate change scenario. The change in forest will be up to 73%, 67% and 62% in the states of Chhattishgarh, Karnataka, Andhra Pradesh, respectively. Calculation of vulnerability index for India indicated that upper Himalayas, and parts of western ghats are most vulnerable to the impacts of climate change, whereas the forests of north east are most resilient. Tropical dry deciduous forests make up to 40% of Indian forest grids and under climate change scenario they are expected to change (Chaturvedi et al., 2011). Regional studies on effect of potential climate change in Himachal Pradesh and western ghats indicated towards a shift in the type of vegetation (Ravindranath et al., 1997; Deshingkar, 1997). Ravindranath et al. (2006) used BIOME4 vegetation model and predicted that by 2085 under climate change scenario vegetation would shift towards wetter type in the north-eastern region and towards drier type in the north-western region. Dry deciduous forests of central India in the states of Madhya Pradesh and Maharashtra are projected to change into moister type due to increase in temperature and precipitation (Ravindranath & Sukumar, 1998). Agarwala et al. (2016) analysed the effect of anthropogenic changes on TDFs of central India and concluded that human interference have serious implications on abundance of tree species.

CONCLUSION

Tropical dry forests are one of the most fragile ecosystems that are facing multiple complex threats. They provide ecosystem services and also are source of livelihood to marginalized people in many parts of the world. Overexploitation, deforestation and fragmentation are the key issues that need to be addressed. These issues are being compounded by global climate change that has serious impact on vegetation composition and distribution, phenology and carbon dynamics in TDF. In order to design conservation and management strategies it is imperative to conduct region-wise research and analysis to study the impact of climate change on TDF. Conservation and restoration measures for TDF should take into consideration the local people, their aspirations and expectations. Mitigation and adaptation strategies should be designed that are country-driven, gender-responsive and address the concerns of local inhabitants. Also, they should be an amalgamation of scientific research as well as traditional knowledge.

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