Chapter 9

Advances in the Assessment of Climate Change Impact on the Forest Landscape

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Abstract

Changing climates threaten the habitats and ecosystems at variable extents throughout the world. Forests are unique habitats and ecosystems that are vulnerable by the consequences of climate change. The climate change causes disturbances, alterations. and shifting on the forests that can be diagnosed at the tree and stand scales, as well as can be monitored and analyzed at the landscape scale. Furthermore, some recent researches concentrate on conveying the forest tree and stand-level shifting and disturbances to the forest landscape level by upscaling. In this study, the climate change impacts on the forest landscapes; principally, the disturbances including the drought-induced mortality, growth and productivity failures, and insect outbreaks are evaluated. Secondarily, climate change-induced alterations of the forest species distributions and forest landscape compositions, dynamics of the forest biodiversity, and tree migrations are discussed by focusing particularly on the relatively recent advances involving the modeling procedures. Ultimately, monitoring the climate change-driven shifting phenology of the forest landscape through the remote sensing techniques is referred in this study. Moreover, the study examples dependent upon the climate-ecological modeling and satellite data assessment of the forest landscapes throughout the world are also referenced. The landscape-scale assessment of the climate change impacts on the forest ecosystems provides integrated and comprehensive approach toward the proposal of sustainable mitigations and solutions to the phenomenon.

Keywords: landscape ecology, ecological models, leaf area index (LAI), biodiversity, tree migration, remote sensing techniques

1. Introduction

Earth's climate had experienced natural alterations due to changes in the solar radiation and atmospheric, oceanic, and terrestrial forces, drivers, and components over the past centuries [1].

However, the anthropogenic effects have triggered the recent climate change since particularly the twentieth century. The emissions of the greenhouse gases, primarily the carbon dioxide that exceeded their average concentrations in the atmosphere, have led to the gradual warming of the earth's surface. Therefore, the biogeochemical processes have been influenced by this change in the climate. The biogeochemical processes have in turn affected the climate contributing its change [2]. Hence, terrestrial ecosystems play an important role in the climate change processes as these ecosystems are significantly vulnerable from the consequences of climate change. Among those terrestrial ecosystems, forest landscapes constitute the major part that is both influencing the climate change and being influenced by the consequences of climate change [3].

Forest landscape consists of the total forest ecosystem within the field of vision that is either comprehended by the naked eyes and/or can be observed through technological instruments and remote sensing techniques. Autumn and winter sceneries from the forest landscapes in Western Black Sea Region of Turkey can be seen in **Figure 1**. The interactions between the forest landscapes and climate are rather intensive and complex principally by means of biogeochemical and hydrological cycles. Basically, climate is effective in the process of exchanging minerals among the plant, soil, and water due to their interactions. Indeed, the forest landscapes are unique ecosystems that are also vulnerable to the climate-induced natural and anthropogenic disturbances. For instance, in particular for the energy-limited environments, increasing temperatures stimulate the photosynthetic and metabolic activities of the forest trees urging their primary productivity and leading them to deposit more carbon that is sequestrated from their environment [4].

Figure 1. Autumn and winter sceneries from forest landscapes in Western Black Sea Region of Turkey (Photos by Melih Öztürk).

This situation makes the consequences of the forest fires more devastating, primarily from the point of releasing huge amounts of carbon dioxide to the atmosphere. On the other hand, the leaf carbon uptake reduces suddenly when the maximum temperature limit occurs [4].

The leaves of the trees are also included into the primary products of the forest landscapes. Hence, increasing temperatures stimulate the growth and amount of the leaves, which are also indicated by some vegetation parameters [5]. Leaf area index (LAI) is one of those vegetation parameters, defined as the one-sided area of the canopy leaves over the projected crown area of that canopy [1]. The LAI plays a key role on determining the level of the growth and productivity as well as on the hydrology of the forest ecosystems [6]. Indeed, the increasing LAI leads to the increment in the evapotranspiration rate to some extent [7]. Therefore, LAI is used as a key parameter in order to predict climate change impact on the growth, productivity, and hydrology of the forest landscape. On the other hand, the temperature-induced increasing metabolic activity of the forest trees triggers their roots to absorb more nutrients and water from the soil [8]. The water absorbed from the soil is eventually lost to the atmosphere through evapotranspiration [9]. As long as this water deficiency could not be met by the precipitation, drought stress occurs for the forest trees under the warming temperatures.

The climate change-induced forest landscape disturbances do primarily involve biome destruction, habitat isolation, and insect invasion. Furthermore, the climate change is able to transform landscape ecology, enhance or reduce photosynthetic activity, interrupt carbon balance, disrupt hydrology and biodiversity, and shift the phenology of the forest ecosystems. Furthermore, land use conversions may be triggered within the forest landscapes as consequences of climate change. On the other hand, the developments and new techniques are introduced in order to monitor and assess the direct and indirect impacts of climate change on the forest landscape. Hence, improvements toward those assessments are discussed together with the new modeling procedures within the scope of this study.

2. Methodology and overall studies

The scientific literature that concentrates and reviews the integrated climate change and forest landscape studies and researches is evaluated and discussed within the concept of this chapter. The world's climate has been changing particularly for the recent decades and is projected to change in the future. Climate change models especially for the forest landscapes and basins are proposed by the recent researchers. Spatial and temporal explicit landscape ecology models that consider patch-corridor-matrix interactions are produced [10]. Hydrological models and associated nutrient cycle models compatible with these climate change models are adapted also for the forest landscapes. Besides, ecological and biodiversity models that project lateral and vertical distribution of the forest species are developed. Moreover, spatially and temporally dynamic land use models are generated regarding the possible land use conversions and reorganization of the forest landscapes. In addition, innovative remote sensing techniques determine the leaf area index (LAI) of the forest landscapes to acquire their phenological and ecophysiological dynamics. These dynamics can be obtained through spatial and temporal analyses of the satellite data under the recent climate change phenomenon and under the prospective climate change scenarios. The LAI can also be indirectly observed and analyzed beneath and just above the canopy through some technological instruments. There are studies conducted for the forest landscapes within the continental scale such as done for Europe [11] and within watershed scale in Turkey [12]. There are also landscape-scale modeling attempts for simulating the dynamics of Oregon (USA) and Alpine (Austria) forest ecosystems [13]. The usage of the LAI parameter in order to define the impact of climate change is gaining importance particularly during the silviculture applications [14].

3. Warming climate

Climate warming indicates the increase in the average annual, seasonal, or monthly temperatures. The warming trends in the climate can be encountered at the local, regional, landscape, and global scales. According to the IPCC reports, global temperature is predicted to increase between 2 and 4°C especially for the second half of this century and is projected to increase toward the next century [15]. Future climate scenarios indicate the heat increases and associated droughts at the regional and global scales. The forest landscapes suffer the warming effects of the climate generally in the form of the drought stress and water deficiency. The warming climate is projected to cause the snow, constitute smaller fraction within the total precipitation which means lower snowpack water storage, and alert for possible summer water deficiency [16]. The summer water shortages particularly imply the drought stress posing threat for the forest trees, stands, and ecosystem.

The role of the forest ecosystems in order to produce microclimate and climate moderating capacity cannot be ignored for diagnosing and understanding climate change impacts on the forest landscapes. For the subalpine and temperate zones of the Swiss forest landscapes, the long-term moderating capacity of the forest canopy reached to 3.3°C being higher below the dense canopy and particularly during the spring when the vegetation period initiated [14]. Climate warming influences the density of the forest canopy and thereby affects the regeneration potential of the forests and the sustainability of the forest landscapes.

3.1. Climate warming and drought stress assessment

Climate change directly puts pressure on these forest ecosystems such as in the form of heat increase and drought stress within the landscape. Increasing temperatures stimulate the evapotranspiration leading to the water loss from the forest soil. The over loss of water from the soil results in the deficiency of soil moisture unless it is met by the precipitation. The long-term soil moisture deficiency alarms the first signals of drought within the forest ecosystem. As is known, the tree roots absorb water and uptake the nutrients dissolved in that water. The soil moisture deficiency restricts the nutrient uptake of the forest trees, which then handicaps the forest growth and productivity and disrupts the landscape health. The prolonged drought may have direct or indirect impacts on the species distribution and composition, biodiversity, net primary productivity, and faunal wildlife of the forest ecosystems [17].

The long-term climate warming stimulates the photosynthetic and metabolic activity of the forest trees extending their vegetation periods. The extended vegetation periods allow the forest trees to sequestrate more carbon and nutrients within their plant organs. Although the concentration of the carbon allocated by the forest tree leaves can be negligible compared to the concentration in the stem [18], outlasting leaves lose more water by transpiration leading to the drier soils. The sustained dry soils cause physiological stress particularly for the water-demanding forest tree species.

The studies emphasize the severity of drought in particular at the Western [19] and Southwestern [20] United States forest landscapes. According to a synthesis of the studies about the drought impacts on the forest dynamics, structure, and biodiversity, the hydrothermal surplus and deficit values are generally referred in order to anticipate the severity of the droughts [19]. They also mentioned about the developed models that would project the forest responses to those drought impacts. Forest landscape models focus on the drought impacts as well as the land use impacts on the forest ecosystems [19]. Additionally, ecological modeling procedures for projecting the land use dynamics and associated hydrological responses under the climate scenarios are proposed [21]. Recently, one of these modeling applications involve simulation of the forest stand dynamics and land use conversions in order to predict watershed water budget [21].

3.2. Assessment of climate change impacts on forest growth, yield, and productivity

The productivity of the forest landscape is particularly dependent upon the basic environmental factors including the light, water, temperature, and site nutrients [6]. These are the main drivers that influence ecophysiology of the forest trees and determine the forest landscape health. Since the temperature and radiation stimulate the forest growth, climate warming especially favors the net primary production (NPP). Most of the studies that focus on the interactions between the climate change and forest productivity have indicated the positive trend of the forest productivity with the climate change [22]. The carbon dioxide is the main determinant factor for such trends. Generally, forests tend to occupy the warmer climates [22]. Leaf area index is used as an indicator of forest growth and productivity and can be used for determining the distribution gradients of the forest tree species [12].

The basic assessment methodology of the forest growth response to climate change at the individual tree and species level is correlating the climate data with the tree-ring width and the diameter at breast height (DBH) measurements. Thus, the effects of increasing or decreasing temperatures, water abundancy or deficit on the tree-ring width changes, and tree radial growth alterations are to some extent analyzed and predicted. The tree-ring width measurements are conducted with the integrated precise instruments and software technologies. Besides, tapes, digital calipers, compasses, and more recently the laser technology serve for the DBH measurements.

The collected individual tree radial growth data provide establishment of a measured tree network at the forest species and stand levels. These forest species and stand-level data together with the climate data can be represented within the regional, landscape, or global scales using definite geo-statistical techniques of geographical information system (GIS) applications. Thereby, the spatial impacts of climate change on the growth and productivity of the forest landscapes are explicitly displayed thanks to the digital maps. Consequently, the validity of all these forest landscape data is able to be tested and analyzed dependent upon the comparison with the satellite data using the remote sensing techniques.

There are many studies in the literature that focus on the climate change impacts on the forest growth and productivity. Based on the tree-ring width calculation of variable forest species, a dendroecological study concluded that the northern limestone Alpine forest landscapes had overall been robust to the climate change [23]. The study insisted that the fir had relatively been drought-tolerant species compatible with climate change, whereas spruce had been the most sensitive species to the drought [23].

3.3. Climate change impacts on forest species distribution, biodiversity, and tree migration

Climate is a significant driving factor for the distribution of the forest species throughout the landscapes. Therefore, biodiversity of the forest landscapes differ based on the alterations among the regional climates [24]. Moreover, dependent upon their climatological requirements; primarily upon the temperature and precipitation tolerability limits, forest trees tend to migrate toward either warmer or colder altitudes or regions. Climate change impacts on the distribution and biodiversity of the forest species are evaluated and analyzed at different spatial scales ranging from individual trees to communities and biomes [25]. The biodiversity of the forest landscapes is affected by the climate change and in turn feedback the climate, encouraging the possible changes [25]. Climate change and land use lead to large shifts in biodiversity within the forest landscapes [25]. The rapid and extreme large shifts will be experienced especially at the ecotones of the semiarid landscapes [26]. One of those landscape-scale large shifts occurred in the 1950s at the Northern New Mexico where forest patches had become fragmented due to drought-induced mortality of ponderosa pines [26]. Possible global warming induces the treeline shift to the upper altitudes and toward the higher latitudes [27]. Such as the treeline shift, climate change has pronounced impacts on the forest tree migration, which is not only related with the genetic characteristics of the species but also considerably associated with the environmental conditions of the forest landscape.

4. Modeling and simulation procedures

Conceptual or numerical modeling and simulation procedures provide integrative comprehension of the forest ecosystems and natural landscape environment. In the recent years, climate change models are the basis for simulating and projecting the climate change impacts on the forest landscapes. Climate change models are particularly based on the atmospheric carbon dioxide concentration change scenarios [28]. The early modeling studies that concentrated on the assessment of the climate change impacts on the forest landscapes date back to almost 30 years ago. However, up to date, then, functions of the models had broadly been dependent upon solely to the climate, almost ignoring the tree physiology and other ecological and environmental factors such as soil characteristics, pests, pathogens, etc. [28]. Indeed, climate may not be only determinant, for instance, to simulate the tree species distribution throughout the forest landscapes.

The developments in the assessment of climate change impacts on the forest landscapes thank to two major procedures; implementation of modeling-simulation methods and application of remote sensing techniques. Modeling procedures principally involve the simulation of drought-induced stresses and phenological and physiological responses to these stresses. Consequently, the forest tree growth and productivity, disturbances, mortality and diebacks, tree migration, redistribution of the species composition, biodiversity alterations, pest and pathogen invasions, and harms are all modeled under the changing climates and related scenarios.

4.1. Drought stress, wind disturbance, growth, productivity, and tree mortality models

Climate change-induced drought and heat stress could shift the tree species composition, forest structure, and geographical distribution of forest landscapes in many regions [29]. The drought essentially causes tree mortality and disruption of patches within the forest landscapes. Therefore, the spatial heterogeneity within these drier forest landscapes impairs regeneration and provokes associated subsequent disturbances [30].

The wind damage to the forest trees is one of the severe disturbances within the forest patches [31]. In order to simulate the impacts of wind disturbances on the forest ecosystems, a process-based model was developed and coupled with the iLand (landscape simulation model), where the level of disturbance was accounted on the individual trees and on forest structure dynamically [32]. The model was tested for simulating windstorm damage on a forest landscape of Sweden, showing that the predicted results were highly compatible with the satellite-driven data [32]. The model was then improved in order to analyze its response to the bark beetle disturbances in a forest landscape under the +4°C climate warming, which is predicted to increase the disturbed area almost threefold [33]. One of the fundamental models that intend to assess the impacts of global changes on the growth and productivity of the forest landscapes is the forest growth model (3-PG) [34]. Referring to the satellite data, the physiologically based process model is used to simulate the response of maximum periodic annual increment (PAI) of forests to the climate change scenarios [34].

Drought stress has direct impacts on the forest landscape dynamics. Out of the models, LANDIS-II, the forest landscape disturbance and succession model, come into prominence that it is used for the analysis of the landscape dynamics [35]. Other empirical models can serve to this forest landscape disturbance and succession model [35]. One of the studies with the LANDIS-II revealed that the drought stress had affected species composition and total biomass in a forest landscape of Wisconsin (USA) [35]. They indicated that the forest tree species had responded to the length of the drought rather than the severity of that drought. The results of the model emphasized the significance of drought on the forest dynamics simulation and carbon storage [35].

The tree mortality may emerge based upon the climate change-induced drought-heat stress and associated ecophysiological failures, pest and pathogen outbreaks, and fires [29]. The realistic assessment of tree mortality within the forest landscapes should not be solely dependent upon the basic climate-tree mortality interaction models but also be supported with field observations. A review of these models can be seen in **Table 1**.

Model name	Focal task	References
3-PG (physiologically based process model)	Forest growth and productivity modeling	Coops and Waring [34]
MAPSS (Mapped Atmosphere-Plant-Soil System)	Vegetation (including forest) density and distribution modeling	Neilson [36] and Bachelet et al. [37]
MCI (combination of MAPSS and CENTURY)	Dynamic global biogeography projection	Bachelet et al. [37]
DISTRIB (empirical model)	Forest community distribution simulation	Iverson and Prasad [38]
DISTRIB and SHIFT (spatially explicit cell-based model)	Predicting colonization potential across fragmented landscape and tree migration	Prasad et al. [39]
FVS (forest vegetation simulator)	Landscape forest dynamics: stand dynamics, species composition, growth, and yield	Crookston et al. [41]
iLand (individual-based biodiversity model using empirical response functions)	Forest landscape biodiversity modeling: tree, ground cover, insect, and beetle biodiversity projection	Seidl et al. [13] and Thom et al. [42]
TreeMig (spatially explicit-dynamic forest landscape model)	Tree migration prediction, considering landscape patterns, reproduction, growth, competition, and mortality	Lischke et al. [43] and Nabel et al. [44]
LANDIS-II (spatially interactive forest landscape model)	Tree species migration, growth, mortality, succession, disturbance, and drought stress modeling	Scheller and Mladenoff [45] and Gustafson and Sturtevant [35]
LANDIS PRO (regional-scale forest landscape model)	Forest composition change due to population dynamics, dispersal, and harvest	Wang et al. [46]

Table 1. Models for assessing climate change impacts on forest landscapes.

4.2. Models of climate change impacts on species distribution, biodiversity, and tree migration

According to a study, the species distribution and biodiversity models that respond to the climate change impacts are summarized until then [25]. The summary indicates that the initiation of these models dates back to the 1990s. The global climate models that indicate the climatic drivers of the forest species distribution and biodiversity assisted the biodiversity models at the stand or landscape scales. Out of these models, the Mapped Atmosphere-Plant-Soil System (MAPSS) that simulates interactions between the biosphere and atmosphere regarding the climate change impacts dates back to 1995 [36]. The model capable of projecting forest distribution considers vegetation parameters such as leaf area index (LAI) and stomatal conductance in order to compute the hydrological balance within the landscape [36]. The equilibrium MAPSS model together with the dynamic MCI model that is an integrated version of MAPSS and CENTURY models were used in a study to simulate the biogeographical distribution of the vegetation across the US landscapes [37]. According to the findings of the study, a moderate rising of the temperature led to the denser vegetation and more carbon sequestration, whereas a large temperature rising resulted in large vegetation shifts and carbon losses [37].

The modeling approaches at the tree species and forest community levels have also become prevalent. An empirical model DISTRIB that relies on regression tree analysis was introduced in order to propose potential future distributions and suitable habitats for 80 forest tree species at the Eastern US landscapes under the climate change scenarios [38]. They predicted that the climatic change would have led to the slight increment in the tree species richness across the landscapes while maples, beeches, and birches would have lost most of their areas under all the climate change scenarios [38]. More than a decade later, the DISTRIB model was applied again for the Eastern United Sates forest landscapes under the future climate change scenarios [39]. They incorporated a spatially explicit cell-based SHIFT model to anticipate the colonization potential of the multiple tree species under the current fragmented habitats and notably the dominance potential of the oaks within the forest landscapes in order to inquire suitable habitats under the influence of the climate change [39]. The integrated model was successful in estimating the colonization potential, proposing that a narrow area of the suitable habitats for oaks would likely be occupied within 100 years [39].

Modeling the treeline shifts assists the scientific knowledge around the comprehension of the impact of climate change at the landscape scale and serves to develop forest landscape management proposals under the possible impacts. According to a study that produced spatiotemporal model for the treeline dominated by mountain pine at the Northern Calcareous Alps in Austria, the spread of the trees was slow due to the low growth rates and long generation terms [27]. On the other hand, in order to assess the uncertainty about the models of climate change effects on tree range distributions, eight models involving the ones of niche-based, process-based, growth index, and dynamic global vegetation were compared [40]. The study concluded that the model conflicts particularly originated from the rising carbon dioxide assumptions, whereas the models reconcile for the range contraction of Scots pine and for the range expansion of some Mediterranean tree species [40]. In a study, forest vegetation simulator (FVS) was adapted to respond to the effects of possible climate change accounting the regeneration, growth, mortality, and climate-induced genetic reactions [41]. According to the projections of the FVS model, the tree mortality tended to influence the stand dynamics within the landscape of the Western USA proposing the need for introducing new model as Climate-FVS [41].

Some of the recent models that intend to simulate the climate change impacts on forest landscape biodiversity not only project the disturbance of tree species but also predict the diversity of ground cover vegetation and insects. The iLand model is one of those complicated forest landscape biodiversity models that simulated the climate change impacts on the tree cover and composition change together with the responses of other organisms including the ground vegetation, spiders, beetles, and insects [42]. The model investigated the effects of the disturbance regime in a national park of Austria, indicating that the increasing frequency and severity of the disturbance had overall been beneficial for the mountainous landscape biodiversity [42].

Difficulty in modeling the forest tree migration under the climate change scenarios arises dependent principally upon the complexity of the vegetation and site parameters. One of the tree migration models at the landscape level is the TreeMig which is a dynamic and spatially explicit forest landscape model considering the reproduction, growth, competition, and mortality of the forest trees [43]. The model was tested for the Alpine landscape of Valais, Switzerland, where sudden and severe temperature declines led to rapid forest diebacks and rising temperatures retarded the species colonization [43]. The forest landscape model, TreeMig, was capable of producing landscape patterns as a result of endogenous and exogenous factors [43]. The TreeMig forest landscape model was then modified to simulate northward migration of the European hop hornbeams along the fragmented and climatically variable Alpine landscapes of Switzerland [44]. They concluded that the interannual climatic changes had significantly influenced the migration potential of the European hop hornbeam trees [44]. Another model that can simulate the forest tree species migration, growth, succession, and mortality under the influence of particularly the climate change, landscape fragmentation, and interspecific competition is the LANDIS-II [45]. In a study at the northern Wisconsin of the USA, the LANDIS-II was applied to inquire the aboveground biomass change and multiple forest tree species migration [45]. According to the results of their simulation, the landscape fragmentation obstructed the forest tree species migration and range expansion [45]. The regional-scale version of the previous model, LANDIS PRO, was run from 2000 to 2300 in order to account for the forest species composition changes due to multiple climate change scenarios and regarding the succession and harvest processes within the Central Hardwood Region of the USA [46]. The LANDIS PRO model predicted that the forest composition had tended toward xeric species rather than mesic species for the regional landscape [46].

5. Remote sensing techniques for assessing climate change impact on forest landscape

The assessment of the climate change impacts on the forest landscapes particularly concentrated on the two issues: modeling and remote sensing techniques. The remote sensing technique is used to monitor the forest growth, productivity, canopy height, and biomass over the past 30 years [47]. The usage of these techniques for the assessment of the impact of climate change on the forest productivity and growth has been gaining prevalence for the last decades in particular [22]. The remote sensing techniques allow the assessment of climate change impacts on the forest landscapes through monitoring the climate change-induced postfire impacts, shifting phenology of the forests trees, ecophysiological responses of the forest landscapes to the climate change, and growth and productivity measurements using the satellite data.

The forest disturbances in the landscape scale are particularly monitored through these techniques. These monitoring processes and procedures have intensively concentrated on the vegetation changes and responses to those disturbances. Forest landscape composition is also affected by the disturbances triggered by the climate change. These disturbances involve the harms caused by the insect outbreaks and windthrows. The remote sensing techniques are relatively able to predict the level of such disturbances. Therefore, these techniques are frequently referred in the researches that investigate the impacts of climate change on the forest landscapes.

5.1. Remote sensing of climate change-induced shifting phenology

The air temperature is generally estimated to increase with the ascending altitude, based on the principle of lapse rate that generally ranges between 0.4 and 1°C per 100 m.a.s.l. [48]. The phenology and ecophysiology of the forest landscape are directly influenced by this air temperature alternating along the altitudinal gradients. Hence, the phenological stages of the forest landscapes including principally the foliation processes; budburst, leaf onset, leaf expansion, and defoliation processes; senescence, discoloration, leaf fall are driven primarily by the climate. Consequently, any change in the climate is possibly to shift the timing of all these phenological processes and patterns.

The remote sensing techniques supply the spatial and temporal monitoring of these phenological stages and patterns of the forest landscape. The relatively key parameter in order to analyze these spatiotemporal changes is normalized difference vegetation index (NDVI) [47]. There have been global studies which concentrated on analyzing the climate change effects of alternating the phenology of the overall vegetation based on their NDVI data [49]. However, the satellite-based data should be validated with the ground-based data. By comparing the field data with the satellite data, a study tried to validate the land surface phenology of the mixed temperate forest at the landscape scale [50]. They used MODIS (moderate-resolution imaging spectroradiometer) and enhanced vegetation index (EVI) in order to inquire phenology along the springs of 2008 and 2009 [50]. The budburst stages were successfully derived by the satellite data which were also compatible with the ground-based data [50].

The insect injuries are relatively the major disturbances emerging as a consequence of climate change. In order to map the forest landscape composition following the post-disturbance by spruce beetle, a study used Landsat satellite data together with an image processing tool [51]. As a result of the study, they concluded that their percent canopy cover model could approximately predict the observed values [51]. The multipurpose vegetation parameter, LAI, is also used as indicator during the remote sensing studies with the purpose of assessing the climate change impacts and associated disturbance impacts on the forest landscapes [52, 53]. The tree mortality rates due to the heat-induced and greenhouse gases can be alerted for a possible climate change [54]. Drought-induced forest diebacks may occur, which can be detected by the satellite data indicating the change in the landscape color [55]. Hence, a study used Landsat imagery in order to detect drought-induced tree mortality in the forest landscape of Central Texas (USA) [55]. Furthermore, the usage of unmanned aerial vehicle (UAV) is among the novel and emerging technologies and techniques [56] that can practically be used for monitoring the phenology and ecophysiology of the forest landscapes affected by the climate change [57].

6. Conclusions and recommendations

Climate change not only influences mechanisms of the forest ecosystems but also directly or indirectly triggers extreme events such as landslides altering the physical structure of the forest landscapes [58]. Therefore, climate change impacts on the forest landscapes should be considered and handled in a broader scale involving forecast of the possible subsequent disturbances and estimate of the ecosystem's adaptation potential. Hence, the determination of the adaptive capacity of the forest landscapes is particularly significant from the point of developing sustainable management proposals for these fragile landscapes [59]. The studies referred in this study not only suggest the existing climate change-associated die-offs, insect and pathogen invasions, and outbreaks but also warn for the future vulnerability to climate-induced tree mortality, physiological stresses, land use transformations, etc.

On the other hand, climate change is a phenomenon influencing the urban forest environment as well as the natural forest resources and landscapes. Although the climate change prevails within both the urban and rural environments, the warm air originating particularly from the human-induced urban heat islands rather affects forest landscapes closer to the urban fringes. Therefore, climate change impacts on forests should not only be addressed within the stand level but also be handled and mitigated at the landscape scale. Consequently, the sustainable forest landscape management objectives could be achieved under the recent and potential climate change phenomenon.

The ecological models for the optimum management of the forest landscapes should be developed and advanced in order to account and anticipate even the latent consequences of the climate change together with the pronounced and apparent impacts. It is suggested that the future model projections about the disturbance regimes on the carbon balance would assist forest management [60]. These models should also indispensably be integrated with the continuous spatial and temporal monitoring procedures of remote sensing techniques based on satellite data and aerial photographs. However, the models that lack field observations and validations are somehow pending questions and uncertainties about thoroughly assessment of the climate change impacts on the forest landscapes. In addition, it is necessary that the independently conducted local and regional studies and researches should be conveyed and gathered for the sake of supporting the global knowledge store on climate change and forest landscapes.

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