FOREST PATHOGENS AND DISEASES UNDER CHANGING CLIMATE -A REVIEW

Muhammad Mohsin Raza*, Muhammad Aslam Khan*, Irfan Ahmad**, Ali Ahsan Bajwa***, Hafiz Muhammad Usman Aslam*, Badar Ahsan Ullah****, and Kashif Riaz*

ABSTRACT:- Changing climate threatens tree health by affecting the likelihood, frequency of occurrence, types and severity of forest diseases caused by diverse pests, resultantly altering the forest ecosystems. The present review covers the relationship between climate and diverse cases of forest diseases and potential shocks of climate change on pathogens and diseases. Biotic diseases, cankers, decays, declines, foliar diseases, root diseases and stem rust of pine have been reviewed with some illustrations of potential disease effects with predicted changing climate. The impact of changing climate on host, pathogen, and their interaction will have frequent and mostly unsympathetic outcomes to forest ecosystems. By employing the proactive and modern scientific management strategies like monitoring, modeling prediction, risk rating, planning, genetic diversity and facilitated migration, genetic protection and breeding for disease resistance and relating results to forest policy, planning as well as decision making, the suspicions innate to climate change effects can be minimized.

Key Words: Climate Change; Diseases; Ecosystem; Forest Management; Pest Management.

INTRODUCTION

Forests are crucial sanctuaries for terrestrial biodiversity, having the importance as an essential constituent of biogeochemical structures of the earth and the resource of vital human's well being ecosystem services (Shvidenko et al., 2005) . In addition, forests are eligible to relieve global climate alteration through their services as net carbon sinks (IPCC, 2012). Over the last three centuries, 40% of the global forest area has been diminished mainly due to anthropogenic activities which predominantly involve the adaptation of forest land to agricultural convention (Shvidenko et al., 2005). Forest areas have declined as populations and economies have grown (Flejzor, 2011), the total earth's land area under forest canopy is less than one-third (Butchart et al., 2010). Agents disturbing the forests such as pathogen outbreaks, insects, drought, fire, introduced species, ice storms, hurricanes, landslides and windstorms can diminish the forests's services provision capacity and commodities, particularly when natural disruption patterns or regimes of these agents are distorted by human acts (Bentz et al., 2010; Dale et al., 2001; Lewis and

* Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan
** Department of Forestry, Range Management & Wild Life, University of Agriculture, Faisalabad, Pakistan.
*** School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Australia.
**** Narcotic Control Division, Government of Pakistan, Islamabad, Pakistan
Corresponding author: aliahsan2195@gmail.com

Lindgren, 2000).

The earth's climate is experiencing a rapid change primarily due to human activity and the burning of fossil fuel (McMullen and Jabbour, 2009). The resulting alterations in temperature and precipitation patterns will directly influence both the natural and modified forests (Kirilenko and Sedjo, 2007) and are expected to result in huge variation in vegetation distributions promptly (Allen and Breshears, 1998). The world's atmospheric temperature has become more warm and will keep modifying further with an unprecedented rate and high frequency (Kliejunas, 2010). Aerosols and greenhouse gases concentrations in atmosphere are getting alter along with modifications in solar radiation and land cover which are the key factors of climate change. The concentration of CO_2, one of the most important noxious greenhouse gases, has ascended considerably since pre-industrial times. Predictions of carbon cycle models indicated that the CO_2 concentration will increase from 379 ppm in 1995 to 970 ppm in 2100. Although, the greenhouse gas emissions linked human sources were soothed, for centuries the warming would prolong due to time lags linked with climatic processes and feedbacks (Kliejunas, 2010).

From 1990 to 2100, the average worldwide temperature is expected to boost from 1 °C to 6 °C which will be potentially seen across much of the United States (Houghton et al., 2001). Scientists have consensus for the profound direct and indirect consequence of changing climate on forest dynamics (Ayres and Lombardero, 2000; Aber et al., 2001; Dale et al., 2001). Recently, in North America, the widespread tree death events have been closely related with changing climate (Kurz et al., 2008; Van Mantgem et al., 2009). Multiple, interacting procedures that were affecting the forests are mainly commenced by climate change (Johnston and Hesseln, 2012). These climatic changes could result in improved forest productivity (Aber et al., 2001); however, increases in the frequency and intensity of wildfires, severe wind-throw events and outbreaks of insects and pathogens, may be more important than any positive influences of warmer temperatures and elevated CO_2 (Kirilenko and Sedjo, 2007). For instance, higher concentration of CO_2 in atmosphere can result in increased water use efficiency and tree growth rates (Rogers and Dahlman, 1993). Similarly, a decreased effect of carbon fertilization on the productivity of older trees over time is expected (Boisvenue and Running, 2006) . In the southern USA, the CO_2 that elevated was revealed to enhance the resistance of host to two most important forest diseases (Runion et al., 2010). This is because, reactions to CO_2 enrichment may vary among locations and species and to increased atmospheric CO_2 a wide scope of reactions should be expected worldwide.

The main objective of this review is to develop a better understanding of forest diseases under changing climate and the management of various forest diseases under the climate change scenarios. The paper has been prepared by reviewing the knowledge of relationships between different climatic factors and numerous pathogens of forest and by monitoring current evidence representing the pathogen and host interactions and climatic change. Forest health and management strategies have also been recommended and discussed in this review that should be incorporated to better approach with diseases of forest and climate change.

CLIMATE CHANGE, FOREST PATHOGENS AND DISEASES

Since the majority of plant disease pathogens are robustly inclined to the environmental conditions and vitality of host, so changings in climate may exert influence over the pathogen, the host and interactions between each other, bringing about changes in disease impact (Table 1). Though, how specific the forest pathogens will react to the changing climate is not sure, existing knowledge allows to illustrate some general inferences (Table 1).

Reactions of forest ecosystems and forest tree pathogens to changing climate are difficult to predict due to substantial uncertainty concerning the extent and type of changing climate that will happen (Millar et al., 2007) . It is hard to evaluate whether climate 'alone' cause tree mortality. This is because, the use of climatic data cannot be presented as definite as that of the pathogens, the scientific society must often depend on incidental confirmation. Information on interactions between the pathogens of forest, the environment and their hosts is limited. It is also evaluated that whether climate changing drives tree death is still more complex. Like, death of trees due to the response of heat and drought has recently been related to change of climate, while intermittent droughts have long been entailed in mortality liberated of climatic alterations. Therefore, it is often unclear whether the climatic effects are direct or interactive. Climatic effects change on adaptation, host physiology and the genetics of population that affect pathogen-host interactions and it will be varied by climate change in ways basically not known. It can be understood based on existing knowledge that tree health will reduce while conducive conditions for some potential pathogens will increase due to changing climate.

The likely impact of changing climate on forest pathogens can be modled by analyzing current relationships between many biotic and abiotic factors and behavior of individual pathogens despite these uncertanities. The environmental conditions have been quantified which can exploit by numerous diseases individually. Impacts of many pathogens on forest trees will exacerbate due to drought stress. Few pathogens like *Phytophthora* occurrence and severity will increase due to rising winter temperatures. Occurrence and severity of foliar pathogens will increase with increasing spring precipitation while stem rust's expansion will stimulate with increasing autumn precipitation. Forecasts for the pathogens whose natural actions or range are chiefly determined by temperature are relatively feasible and credible. It is very complicated to forecast how changing climate can affect pathogens dependence and its interactions with some other organisms like insect vectors (Lonsdale and Gibbs, 1996). Validation of predictions regarding host, pathogens and climate interactions is difficult due to insufficient data (Runion et al., 2010).

PREDICTIVE MODELING FOR DISEASES

Future distribution of forest trees

Table 1. Impact of changing climate on forest diseases and pathogens

Changing climate	Forest diseases and pathogens
Increasing latitudinal and elevational ranges	Some diseases may allow to expand their latitudinal and elevational ranges due to increment in temperature and variations in precipitation, perhaps whilst contracting to another place, although models oftenly forecast a decline in the geographically potential division of different tree species of forest (Rehfeldt et al., 2009) or certain diseases (Venette, 2009) as an outcome of changing climate. If the migration of tree species facilitated to new locations, new diseases can be expected to affect those trees. A debate regarding the infectious diseases of humans has also been stimulated due to this question (Epstein, 2010). In this regard, pathogens might play key role for mitigation in forest trees.
Modification in epidemiology	Climate change will alter the epidemiology of plant diseases. Forecasting of disease outbreaks (epidemics) may also become difficult. Although, climate is not going to change overnight but current changes are very drastic and abrupt.
Alteration in biological synchronicity and the life cycles	Changing climate will influence the biological synchronicity and the life cycles of numerous forest trees and pathogens, leading to alterations in the circulation and phenology of several events like bud break in host trees, spore releasing by certain pathogens and insect actions that act as a vectors of plant pathogens; so this may considerably modify severity and incidence of diseases.
Severe attack	Pathogens characteristically affecting water stressed host trees are plausible to have a severe effect on forests in regions having reduced precipitation.
Uncertainty in evolution	In an abruptly changing climate, the rates of evolution of forest pathogens and associated host resistance may abruptly fluctuate.
New pathogens	Climate change may facilitate invasion by new non-native pathogens. Novel epidemics may occur as a result.
Pathogen migration	Most forest pathogens will tend to travel to regions where the climate is appropriate for their endurance and rapid reproduction rate than forest tree species.
Increase in over wintering survival of pathogens and diseases	Many forest pathogens currently are restricted by winter temperature, and continued increases in temperature are predictable to be maximum during winter. Accordingly, both over-wintering survival of pathogens and disease severity are likely to increase.

can be projected through currently available models by using climatic variables (Hamann and Wang, 2006; Rehfeldt et al., 2006) , but only some of them are exclusively developed to predict forest pathogens. For instance, in Australia a dynamic simulation model naming CLIMEX was developed (Sutherst et al., 1999) and it was used for forecasting the impending geographical dispersion of forest tree species and also for investigating the potential dispersion of numerous pathogens (Brasier and Scott, 1994; Scherm and Yang, 1999; Venette and Cohen, 2006). Moreover, in Portugal, progress in modelling prediction for projecting the pine wilt disease was made under PHRAME project (Evans et al., 2008). Furthermore, Manter et al. (2005), developed a disease predictive model based on temperature for Swiss needle cast in combination with geographical information systems (GIS) linked climate databases for the estimation of different disease levels in USA.

The following sections describes a number of instances of possible effect of the disease with predicted changing climate comprising the impact of weather on host, pathogen and disease.

Abiotic Disorders

Extreme temperatures, air pollutants, precipitations, nutrient deficiencies and toxicities and water scarcity are engendering abiotic forest diseases which are not limited to these factors only. Forest stands are suffering from unusual high levels of stress due to changes in climate including increased temperatures and evapotranspiration rates, inappropriate rainfalls, and extreme weather (Sturrock et al., 2011). Plant diseases are affected by several abiotic environmental factors in numerous ways.

Firstly, environment directly engendered to abiotic diseases on the host. Typically, environmental extremes (droughts, high or low temperatures) have a hazardous impact on host species (Desprez-Loustau et al., 2006). Photochemical reaction rates and humidity may increase due to average temperature increments, which may result in higher ozone concentrations (Sitch et al., 2007). Tree susceptibility to root diseases is likely to increase along-with decrease in plant's ability to sequester CO_2 under higher ozone concentrations (James et al., 1980).

Secondly, host vulnerability and pathogen's aggressiveness are mainly influenced by temperature and moisture. For instance, *Phaeocryptopus gaeumannii* causing Swiss needle cast is strongly influenced by winter temperature and its growth gets affected (Manter et al., 2005). Similarly, *Sphaeropsis sapinea* on pines was positively associated with water stress (Bachi and Peterson 1985; Blodgett et al., 1997; Paoletti et al., 2001). Aspen (*Populus* spp.) forests lose resistance to fungal cankers due to droughts of 1960s and 1980s in northwestern Alberta (Hogg et al., 2002). Moreover, prevalent mortality of pinyon (*P. monophylla*), juniper (*J. osteosperma* and *J. occidentalis*) in Southwestern United States is correlated with prolonged droughts and disease and insects are accountable for native pinyon mortality (Shaw et al., 2005).

Thirdly, abiotic elements also play role as contributing, provoking and predisposing agents in tree declines (Manion, 1981). Tree's carbohydrate reserves deplete while susceptibility to pathogens and insects increase under such stresses (Wargo and Hack, 1991). Severe droughts result in seedlings and sapling mortality. Mature trees have deep roots along with considerable reserves of nutrients and carbohydrates due to which these are resistant to water limitation. Though, prolonged droughts may render even adult trees vulnerable to diseases and pathogens (Joyce et al., 2001). With rising temperature, tree mortality become more common in response to drought. Regional scale mortality of top storey trees which rapidly would alter land cover is of particular concern, food web and ultimately ecosystem function. The impacts of such variations would remain for decades (Breshears et al., 2005; Folke et al., 2004).

Trees stressed by climatic extremes especially prolonged summer droughts are more vulnerable to pathogens such as fungi dependent on host stress, like latent colonizers of sapwood, root pathogens and wound colonizer (Broadmeadow and Britain, 2002; Desprez-Loustau et al., 2006; Lonsdale and Gibbs, 1996; Redfern and Hendry, 2002).

Stem (Canker) Diseases

Death of segments on branches of trees and on main trunks as well results from canker which is due to death of bark tissues by certain plant pathogens. Though several cankerous pathogens are proficient to attack healthy trees, numerous canker-causing fungal pathogens likely to damage previously drought and heat stressed trees (Schoeneweiss, 1975; 1981). Epidemics of such diseases are uncommon (Schoeneweiss, 1981). Interestingly, a positive correlation between drought and disease or synergistic effects of disease and drought has been reported in published literature. Mostly, facultative pathogens such as *Botryosphaeria, Sphaeropsis, Cytospora, Septoria* and *Valsa* cause canker diseases (Desprez-Loustau et al., 2006). It has also been revealed from studies that severity of diplodia shoot blight (*D. pinea*) and severity of *Sphaeropsis* shoot blight (*S. sapinea*) has potentially correlated with aquatic stress (Bachi and Peterson, 1985; Blodgett et al., 1997; Paoletti et al., 2001). Moreover, water stressed trees inoculated with *Septoria musiva* resulted in larger cankers than those in non-stressed trees (Maxwell et al., 1997). *Fusarium circinatum*, *Biscognauxia mediterranea* are other well-known examples of tree-canker-causing species.

Currently, cytospora canker (*Valsa melanodiscus*) is in an severe epidemic condition in the western North America comprising the southern Rocky Mountains and Alaska (Worrall, 2009). Furthermore, there is over 60% of the standing stems are diseased or dead in Colorado and its adjoining areas. Recent data suggests that warm temperatures in mid summer are closely related with host mortality and severe canker growth.

Incidence of many canker diseases may change under climate change. Drought and heat stress to forest and urban trees bolster the establishment of numerous canker-causing fungi (Boland et al., 2004; Broadmeadow and Britain, 2002; Schoeneweiss, 1975; Sturrock et al., 2011). For instance, increment in drought stress leads to increase the incidence of *S. sapinea* on pines.

Notably, some other canker causing pathogens including *Cryphonectria cubensis* on *Eucalyptus* spp., and *Thyronectria austroamericana* (Speg.) Seeler on honey locust (*Gleditsia triacanthos* L.) may decrease its incidence under changing climate. Elevated rain showers are associated with incidence of these pathogens, and their hosts become drought stress resistant to some extent (Desprez-Loustau et al., 2006).

Root Diseases

Among major factors that affect emergence and spread of certain root diseases, tree stress caused by root diseases is quite remarkable. *Armillaria* spp. and *Heterobasidion annosum* are examples of root pathogens that have been reported from western forest conifers and become very serious for hosts already under stress conditions. Climate change may also serve as a contributing factor causing losses to the tree health and vigour in such stressed situations. Moreover, the relative fitness of some mycorrhizal fungi and other pathogens may be altered that have suppressing effects for root disease. The climatic changes including changes in soil temperature or moisture may reduce such species from their protecting effects (Broadmeadow and Britain, 2002), thus rendering the trees vulnerable to attack by different pathogenic species. In such worst cases, the conditions may become even worse by simultaneous increases in temperature coupled with decreases in precipitation thus supporting the spread of such diseases destroying the forests.

Declines

In the 1930s and 1940s, decline of western white pine (*Pinus monticola*) was experimentally observed in the region of Pacific Northwest. Shallow soils as predisposing factors having low moisture were found associated with decline alongwith the contributing factors of canker pathogens and root deterioration from *Armillaria* root rot (Leaphart, 1958). Lower regional precipitation and higher temperature than the past 280 years was indicated between 1916 and 1940 from climate records (Leaphart and Stage, 1971). Therefore, with shallow soils and fungal attack as contributing factors, drought was indicated as an inciting element in the pole blight.

Yellow-cedar decline (*Chamaecyparis nootkatensis*) has been occurring on about 200,000 ha for the last hundred years in Southeast Alaska and British Columbia (Hennon, 2005; Wittwer, 2004) Studies revealed the association of yellow-cedar decline with low snow-pack in the spring and winter, and postulation that snow shelters yellow-cedar from harsh weather found reliable. Yellow-cedar decline was constantly correlated with seasonal or cyclic air and soil temperatures, but it was correlated with aluminium toxicity, calcium deficiency, drenched or acidic soils. The areas having lower temperatures in winter higher in spring or summer and greater daily ranges were associated with greatest yellow-cedar mortality. Warm spring days interposed with overnight frost damaged the roots of the said trees without the snow's protection (Schaberg et al., 2008). Thus, currently, decline is found primarily due to predisposing factor of climate change (climate warming). (Hennon et al., 2008).

In Nevada, Utah and Southern Colorado, sudden aspen decline, the premature aspen stands death (*Populus* spp.), has begun recently. Severe and rapid branch dieback along with crown thinning is the characteristic symptom of the decline. During 2000-05 severe and wide-spread drought resulted stress in the aspens, mainly in mature trees at lower altitudes, reducing the tree's resistance to infestations and secondary infections. The current perception of the said decline revealed its correlation with contributing factors (secondary insects and pathogens), inciting factors (warm and dry conditions) and predisposing factors (like low elevations, mature trees, open stands and south to west aspects)(Worrall et al., 2008).

Similarly, worldwide decline of several *Quercus* spp. is resulted by the interactions between environmental stressors (flooding, drought, pollution and lower winter temperatures) (Brasier and Scott, 1994). as well as simultaneous attack of pathogens (e.g., *Phytophthora* spp. and *Armillaria*). Since 1900, extended decline and death of oak plants has been recorded in the USA and throughout Europe (La Porta et al., 2008). Moreover, a quotable example of such declines is the oak decline prevalent in the Mediterranean regions of great Europe (Brasier, 1996). In Mexico, studies focused on oak decline revealed that water deficits and low temperatures cause stress and result in death of oaks.

Phytophthora Species

The genus *Phytophthora* known worldwide for bringing about economic losses by causing serious damages to diverse plant families, including forest trees, leading to natural ecosystem disruption. Some of the pathogenic species of this genus are capable of multiplying at unprecedented rates increasing inoculum levels in a short time span and show aggressiveness when temperatures are relatively mild to warm. *Phytophthora* epidemics in forest and agricultural systems are a cause of concern throughout the globe. It has been observed that climate changes like even mild increases in winter temperatures may support survival of *P. cinnamomi*, adding to increased negative impacts from *P. cinnamomi* (Kliejunas, 2010). Such pathogenic species are deemed as serious risks in the woods of European countries like UK (Brasier, 1996; Brasier and Scott, 1994). For example, *Quercus robur* and *Q. rubra* are more prone to such pathogens if favorable conditions are found for their growth and multiplication.

Leaf Diseases

Pathogens that cause foliar diseases are most likely to be influenced by changing climate because they are strongly prone by weather. Changing annual weather patterns usually results in variation of severity of these “threshold diseases” (Hepting, 1963), which is probable to increase in warmer and wetter areas. In contrast, severity of several foliar diseases will decrease due to increasing droughts. There is a synchronicity between the emergence and the newly developed tissue of host plants and the sporulation timing of many foliar pathogens. Changing climate will also favour the epidemics of foliage diseases where it is favouring the foliage of vulnerable hosts during conducive conditions for the pathogen. Higher concentrations of CO_2 increase pathogen fecundity and host growth (Chakraborty and Datta, 2003; Chakraborty et al., 1998;). The majority of the foliar pathogens is likely to increase in occurrence and severity as temperature and precipitation increase in late winter and early spring (Kliejunas 2010). Inadequate information on weather and specific foliar diseases interactions is available, while general implications depends upon reliance of these pathogens on environmental conditions which are known. If late winter and spring become warmer, the severity and incidence of majority of the foliar diseases will probably increase, but may decrease in drier summer (Broadmeadow et al., 2005).

The widespread Swiss needle cast (*Phaeocryptopus gaeumannii*) of Douglas fir is still persistent in the coastal belt of Oregon (Boyce, 1940). Though, previously it was considered as a minor disease by a weak pathogen, but in the early 1990s a severe outburst of the disease was reported (Hansen et al., 1988). Its occurrence in the Pacific Northwest (usually occurring at low elevations) is also positively correlated with leaf wetness hours during spring to autumn and degree-day accumulation during winter (Manter et al., 2005). From January to March since 1966, the average temperature per decade is approximately increased by 0.2°C to 0.4°C in the coastal area of Washington and Oregon, signifying that changing climate might be influencing the severity and distribution of the disease (Stone et al., 2008). The disease fluctuate with changing climate patterns. In southern British Columbia, a positive correlation was found between relative abundance of P. *gaeumannii* and spring precipitation (Hood, 1982) while in New Zealand, severity of *P. menziesii* (non native) was positively correlated with winter mean temperature explaining about 80% variability in damage and infection (Stone et al., 2007).

Marssonina leaf spot is another foliar disease, caused by *Marssonina* spp. It infects poplar trees (*Populus* spp.) and the number of rain days of summer affects the occurrence of this disease. Reduced rainy days reduces the incidence of this disease (Kliejunas, 2010). Reports exist about increased damage to *Pinus ponderosa* from a pathogen *Davisomycella medusa* during drought (Wagener, 1959). The abundance of the said pathogen was affected in 1999 by an unusually wet summer. A couple of subsequent drought years in San Juan National Forest in Colorado provided favorable conditions for that pathogen to grow and kill the infected needles of ponderosa pine (Kliejunas, 2010).

CASE STUDY-STEM RUST OF PINE

Among different fungal diseases, the population of pine-stem-rust, caused by *Cronartium* spp. has been affected by climate change. It belonged to Asia but spread to different parts of Europe in the mid 19^{th} century and has badly affected tree health. Climate change has also caused changes to the distribution of blister-rust of white pines in the Western North America, which is caused by C. *ribicola* (Mielke, 1943). The spread of above mentioned fungal pathogens is dependent upon the biotic and abiotic factors including the weather and the vigor of the host which are ultimately affected by the changes in climate. Climate change from cool weather to aridity or drought reduces the relative abundance of these pathogens. C. *ribicola* infects the leaves of the host and gains entry through stomata but in case the stomata are close, the chances of infection will be reduced, hence all those factors that affect stomatal opening influence the infection (Kimmey and Wagener, 1961).

Numerous epidemiological models have been proposed for the prediction of blister-rust of white pine outbreaks (McDonald et al., 1981) all of which reflect that temperature and humidity that affect the epidemiology of the said pathogenic diseases. Rusts are the most important diseases that accommodate for a wide range of weather conditions and their tolerances are still unknown. Mainly the rust incidence will be determined by the distribution of host under a changing climate. Rusts are considered as the most important cause of destructive and lethal diseases (Kliejunas, 2010). Typically, rusts increase in intensity and distribution in “wave years” during which the weather conditions are particularly favorable for infection, sporulation and dispersal. Moreover, as climate changes, the frequency of such wave years is expected to change.

ASSESSMENT AND MITIGATION STRATEGIES

Impact of climate change on forest ecosystems has been predicted using several models. Individual pests response to changing climate is predicted using some of these models (Logan et al., 2003). For instance, response of *Phytophthora cinnamomi* (Desprez-Loustau et al., 2007). and *Phytophthora ramorum* (Venette and Cohen, 2006) to climate change was explored using CLIMEX. Unlike some sophisticated climatic models, many other models does not consider all important components participating in climate change effects. Resent climatic model predictions don't include insect and pathogen impacts on vegetation, and similarly most of the models don't integrate the effects of pathogens as climate change agents (Folke et al., 2004). Although, it is clearly observed that current host-pathogen interactions will be alter by changing climate.

Little investigations on climate and disruption has been reported while impacts of individual disturbances like forest pathogens on forest structure and mapping have been excogitated (Dale et al., 2001). Therefore, its complicated to forecast the extent to which magnitude or frequency and severity of disturbaces will impact (Loehle and LeBlanc, 1996). Most of the previous work concentrated on impact of an individual disorder on host tree, or the relation of single trouble and climate has been reported, however inadequate information concerning changing climate shocks on forest pathogens is available. Mostly, climate change scenario doesn't account abiotic stresses, role of pathogens and their synergistic relations with host (Scherm, 2004). Hence, there is agreement that changing climate will likely stress trees and make them prone to insects, pathogens, and emerging diseases (Brasier, 2005).

An adaptation of the pathogens (sporulation and growth rate changes, modifying phenology) and their hosts (host resistance) and changes in physiology of pathogen-host interactions resulting from the climate change. For instance, there is an increase in CO_2 concentrations will affect plant diseases by varying host anatomy and physiology, likewise the greater aggregation of carbohydrates in leaves, lowered concentration of nutrients, additional layers of epidermal cells, more waxes, greater number of mesophyll cells and increased fiber contents (Chakraborty et al., 1998). Inceptive growth of pathogen will delay because of the alterations in host susceptibility and pathogen virulence increased richness of pathogens due to elevated CO_2 which are considered as significant effects of higher CO_2 concentrations (Coakley et al., 1999). As the concentration of CO_2 is increased, it may also increase the density and size of the tree canopy, resulting higher micro-climate relative humidity following an increase in rust and other foliar diseases (Manning, 1995).

Additional effects of climate change are shifts in geographical distribution of pathogen-host and changed pathogen impacts on host (Coakley et al., 1999). For instance, range extension of *Phytophthora cinnamomi* a subtropical pathogen to north. In certain regions, rising temperatures may bolster insect vectors as well as other pathogens, engendering more damage to the hosts and to the forest ecosystems. Some changes in host trees due to climatic alterations especially host resistance being overcome very quickly because of quick pathogen progression. Hence, such host exposure to pathogens may lead to greater than expected ecosystem damage. Some studies indicated that with local warming and drying, the net source of carbon will increase in subalpine forests (Kueppers et al., 2004). A greater activity by decay fungi has been seen due to rising temperature which potentially reduces forests carbon sequestration. Literature is available including the impact forest decline diseases encompassing yellow-cedar decline and pole blight on tree species under changing climate that affects site conditions and host physiology.

The synchrony and interactions developed over time are critical constituents of the sustainable ecosystems presented under existing climatic conditions. These components will change, as the climate changes, resulting in alterations in pathogen-host interaction. The failure to consider and also include detrimental changes such as warmer temperatures favored an increase of pathogenic species or increased number of insect species that are capable of vectoring pathogens in the climate change models where the data are available, means that those models are underestimating, or in some cases overestimate, the effects of climate change on forest ecosystems. All the crucial components should be included in models for adequate predictions.

Herein, different categories of management strategies have been suggested. Only a portion of full scope of forest management impacts has been covered here. Only key points concerning the greatest influence of forest health agents have been discussed here whereas application of these tactics will vary, depending on several factors especially 'state of science' to support these activities, economic situation, awareness and other existing resources alongwith proposed resource management objectives.

Monitoring

Monitoring the spatial incidence patterns of forest disease pathogens in relation to both the ranges of annual weather patterns and host trees will inform adaptive management. Moreover, the consistency of monitoring data will be maximized if systematic surveys of tree health, growth and mortality are conducted by trained personnel, ideally at the stand, landscape and watershed levels, at regular intervals. By coordinating, monitoring with disturbance agents, the ability of management activities can be effectively employed for long-term management of forests. Data regarding climate and forest disease outbreaks should be monitor using satellite imaging following krigging for authentic results and better understanding.

Modelling Prediction

It is difficult for forest professionals to predict and plan for future while depending upon previous experiences and observations, whereas environmental conditions are changing abruptly (Sturrock et al., 2011). New statistical modeling tools should must develop via which true picture of the story can be depicted. (Hamann and Wang, 2006). developed powerful climate models coupled with environmental envelopes to forecast the potential range of changes across a landscape. Under climate change, well integrated models of varied phenomena can guide management of forests when ranging from pathogens to climate to vegetation. Such models exist for climate, forests and forest pathogens, and synthesizing and analyzing these models may be the best way to evaluate events that might occur in the future (Logan et al., 2003). Modelling climate envelops, pathogens, alongside host reactions to climate, can therefore raise power to forecast disease outcomes.

Planning

Jurisdictions of forest health strategies must be maintained and adequately funded. Personals should review and modify relevant legislation and policies to make sure that the forest health problems can be responded effectively and quickly (Woods et al., 2010). The success of management to diminish the potential hazardous effects of climate change on the forest pests on large spatial scales rely upon the synergistic effects of some other major turbulences, such as wildfire (Lertzman and Fall, 1998). Changing climate engendered to enhance the tree mortality by pathogens and it may increase the severity and occurrence of fires (Kliejunas, 2010).

Risk Rating

Risk and hazard-rating systems should be in place, and applied, in advance of disease epidemics (outbreaks) as these are essential components of forest health strategy. These systems should be a priority for forest health research and development due to their usefulness in predicting future pest impacts under climate change. However, integrating bio geoclimatic zone variants with historical occurrence can be helpful momentary.

Genetic Diversity and Facilitated Migration

Increased species and genetic diversity in combination with facilitated migration is one of the most effective, efficient, and durable methods to maintain healthy plantations in the face of climate change (Millar et al., 2007; O'Neill, 2008). Planting species and populations (seed lots) that adapt to future climatic fluctuations preserve the host-pathogen balance in the forest ecosystem. The facilitated migration of tree species provides an opportunity to increase stand resilience and reduce vulnerability to pathogens because most forest pathogens are species specific, so the simple act of increasing the number of species directly reduces the risks of a plantation, and assist to attain management goals.

Genetic Protection and Breeding for Resistance

The formation and maintenance of forests with various species and age classes can help to maintain resilience to mortality and reduction in growth rates of trees in response to climate modification and diseases (Sturrock et al., 2011). Gene conservation will be critical as climate change, both for maintaining and enhancing the resilience of forests, and for the hope of improving forest level resistance to pests (Yanchuk, 2001). whilst successful resistance breeding programmes in trees are not common (Hunt, 2004). For the forest trees, breeding programmes can promote disease resistance, genetic diversity and tolerance to environmental stresses. The successes through gene conservation and tree breeding for resistance required decades of development. With changing climate, factors affecting the host-pathogen interactions are changing quickly, generally in favor of pathogens (Logan et al., 2003). Such rate of changing climate might exceed the current capability of breeding programmes to face the drastic effects of these fluctuations on forest trees. The unprecedented level of uncertainty of climate patterns, host conditions and pathogen dynamics, signals to investigate and adopt resistance mechanisms that will provide a general pathogen tolerance or resistance to forest trees (Woods et al., 2010). A wide range of fungicides may be an effective method of controlling forest diseases in natural forests and in forest nurseries, especially in the short term, despite negative public perception.

CONCLUSION AND RECOMMENDATIONS

The death rate of forest trees potentially attributable solely to climatic fluctuations and it is a severe challenge to forest business and our ecosystem. Impacts of changing climate on forest tree hosts, pathogens, and their interaction will have adverse and hazardous consequences to forest ecosystems. Climate change will alter the duration, intensity, frequency and timing of disturbances (including drought, fire, introduced species, epidemics of insects and pathogens, ice storms, windstorms, hurricanes and landslides) in forest ecosystems. It will affect the geographic distribution of forest pathogens generally bolster the pathogens in disease infection. A proactive and scientific approach will be required to cope with this issue. We recommend different categories of strategies to manage forest disease under climate change scenarios: monitoring, modeling prediction, planning, risk rating, genetic diversity and facilitated migration, genetic protection and breeding for resistance. These strategies have been implemented to manage several forest diseases in USA. Risk assessments developed previously for invasive and the emerging diseases that can provide a framework for devising and giving data on interactions between forest disease and climate modification. Modelling offers the best approach to make timely predictions for management of forest diseases under changing the climate. To have the best possibility of success under the climate change era, each of the suggested managing strategies will require to varying degrees: the development of tools and techniques; an informed conversation about research needs and integration of results when the research is done; the prioritization of research needs by using risk assessment and risk analyses; and the development of clear and solid links to forest policy.

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AUTHORSHIP AND CONTRIBUTION DECLARATION

S. No	Author Name	Contribution to the paper
1.	Dr. Muhammad Mohsin Raza	Conceived the idea and prepared draft
2.	Dr. Muhammad Aslam Khan	Technical input at every step
3.	Dr. Irfan Ahmad	Overall management of article
4.	Dr. Ali Ahsan Bajwa	Overall management of article
5.	Hafiz Muhammad Usman Aslam	References
6.	Dr. Badar Ahsan Ullah	Tables and References
7.	Dr. Kashif Riaz	Technical input at every step

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