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Climate Change

Plant species responses to climate change: a review

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ABSTRACT

Climate change is a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time period. Global warming influenced plant species response mechanisms including phenology shift; species range shit; diversity and interaction of communities; structure and dynamics of ecosystem or extinction. Highest phenology shift showed an advance of 5.3±0.9 decade^{-1};

and lowest phenology advancement was revealed to be 1.9 days decade^{-1}. The highest species range shift reported is 17.6km and 29.4±10.9m decade^{-1} pole ward and towards higher elevation respectively; whereas the lowest showed to be 6.1±2.4 km and 1-4m decade^{-1} pole ward and towards higher elevation respectively. Phenotypic plasticity is also crucial phenomenon which could help plant species respond to changing climate in situ.

Key Words: Climate change; Phenology shift; Phenotypic plasticity; Range shift

1. INTRODUCTION

Climate change is an alarming concern for both scientific community and layman. Because it fundamentally controls the distribution of ecosystems, species range and process rates on earth (Grimm et al., 2013). Climate change is defined by IPCC (2007a) as "*a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer which could happen either naturally or man-induced*". The UNFCCC (1992) defined it differently as "*a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods*". The increase in human population, which is more than 7 billion these days, and predicted to be above 10billion by 2050 (FAO 2015), is demanding extremely high resources. This leads to the overexploitation of natural resources (both renewable and non-renewable) and expansion of industries, causing climate change, is severely affecting the biodiversity in several ways (Gupta, 2015). However, IPCC (2007a) defends urbanization and land use system in global climate change contributes negligible impact, less than 0.006℃ per decade over land and zero on the ocean.

The global climate is changing at an alarming rate in human history causing droughts and flooding, for example, which affects both the economy and ecosystem maintenance. It is not rational to deny the existence of climate change (CSCC 2001; IPCC 2007a) and is often perceived as human induced modification of the climate (Franklin et al., 2016). One of the major components of climate change is temperature. Even though it is not the sole determinant of climate change, it has a profound impact on climate change. Walther et al. (2002) stated that the Earth's climate has warmed by 0.6℃over the past 100 years and 10% decline in snow cover in the 1960s. It is terrifying that the Earth's temperature would, with uncertainty, increase by up to 7℃ in the coming 100 years (IPCC 2007a). Hansen et al. (2016), reported that the global surface temperature in 2015 was +0.87℃ (~1.6℉) warmer than the 1951-1980, making 2015 the warmest year in history. These phenomenon resulted in several changes including phenology (Cleland et al., 2007; Doi and Katano 2008; Sheridan and Bickford 2011); range of species distribution (Sheridan and Bickford 2011; Walther et al., 2002);

diversity and interaction of communities (Walther et al., 2002; Sheridan and Bickford 2011); structure and dynamics of ecosystem (Walther et al., 2002) or extinction (Barnosky *et al.*, 2011; Parmesan 2006). Apart from the interactions happening in the communities, species exhibit individual tolerance and adaptation mechanisms to climate change which could have broad scale disruption of ecological communities and trophic structures (Stralberg *et al.*, 2009). However, responses by individual species to climate change are not isolated; they are connected through interactions with others at the same or adjacent trophic levels (Walther 2010).

The objective of this paper is, thus, to review plant species response to climate change with special focus to: phenology (time), species range shift (space) and phenotypic plasticity.

2. PHENOLOGICAL SHIFT

Phenology is the seasonal pattern of activities, life histories, of an organism. It includes the critical stages of life cycles. The International Biological Program (IBP) defined phenology broadly as "*the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species*" (Lieth 1974). Phenological change in response to climate change is not uncommon in several taxonomic groups and life forms of plants (IPCC 2007b; Parmesan and Yohe 2003; Root et al., 2003).

Variation among species in phenology is vital in avoiding competition (Cleland et al., 2007) which could help them respond better to climate change because of temperature influence (Hansen et al., 2006). However, it has to be noticed plants can also respond to other environmental factors, for example seasonal variation in photoperiod (Edwards and Richardson 2004). Studies revealed that the highest phenological advance occurred in early spring (Clealand *et al.*, 2012; Parmesan and Yohe 2003). Monitoring studies tracking phenology changes due to climate change have been conducted by Root *et al.* (2003) and showed an average advance of 5.1 day per decade over the previous 30 or more years. Similarly, IPCC (2007b) reported that early spring has been advancing at a rate of 2.3-5.2 days per decade since the 1970s. Furthermore, Parmesan and Yohe (2003) reported 62% of the species in their study showed Spring phenology advancement whereas 9% phenology delays in Spring. Onset of autumnal phenological events were reported somewhere else, but these shifts are less pronounced and show a more heterogeneous pattern (Walther *et al.*, 2002), but could be noticeable as the globe is continuously warming. Menzel and Estrella (2001); and Menzel and Fabian (1999) in Europe reported leaf color changes shows an advance delay of 0.3±1.6 days per decade and the length of growing season have increased by up to 3.6 days per decade over the past 50 years. Phenological shift due to warming could increase the primary productivity of an ecosystem (Bertin 2008), since longer growing season are more productive than shorter growing seasons (Lieth 1974). However, plants have to control the temperature induced resources limitations, e.g. water. Defila and Clot (2001) and Menzel (2003) also reported an advancement of 1.9 days decade^{-1} and 1.6 days decade $^{-1}$ respectively. The estimated mean of days per decade for all species in the study, 694 species, revealed that the change in spring phenology is 5.3±0.9 (Root and Hughes 2005). The interpretation of these changes is, however, not an easy task (Visser and Both 2005).

Phenological shifts are influenced by altitude (Defila and Clot 2001) and expected to be more sensitive at high latitudes as well (Root and Hughes 2005). The authors claimed phenological shifts were predominantly recoded at higher altitudes. Considering the phenological adaptability to changing temperature, however, all plant species don't respond the same way. In species 'non-responsive' to temperature, phonological behaviour is regulated by a variety of different genetically controlled mechanisms (Briggs 2009).

Even though Root and Hughes (2005) claimed that phenology shift is a short term primary response, it could influence several interactions in the community viz. plant pollinator interactions. Plant-pollinator mismatches were reported by several authors (Fabina *et al*., 2010; Hagl and *et al*., 2009). Different trophic levels may shift their phenology to different magnitudes, revealing asynchronies in timing within the ecological network (Walther 2010).

3. PLANT SPECIES RANGE SHIFTS, COMMUNITY COMPOSITION AND COMMUNITY RESHUFFLE

Climate is one of the determinant factors for species distribution. Species ranges shift due to climate change are determined by: abiotically limited relicts in which their distribution and physiological activities is constrained by lack of sufficient environmental variables related to climate change; biotically limited relicts in which biotic perturbations such as competition is minimal for climatic reasons; and biotically sustained relicts which require a host or mutualist limited to climate change for their existence (Hampe and Jump, 2011; Islam *et al*. 2016).

Since the mountains are predicted to be warmed by three times higher than the global average rate of warming recorded during the 20th century (Nogue´s-Bravo et al., 2007), the majority of researches on range shifts emphasizes on mountains (Cannone and Pignatti 2014; Grabherr *et al*., 1994; Pauli et al., 2007). This could be also the restricted movement of living organisms from mountains and pockets in extreme temperatures (Sgro *et al*., 2011) which leads to extinction (Thomas et al., 2004). Surprisingly, the majority of the researches on plant species response to climate change are also conducted in Europe and North America.

Several species are relocated from their native place without human assistance in response to climate change (Parmesan 2006). However, a particular species has a specific threshold of environmental variables for its phenology. The range of species and their composition has been changing due to several factors, mainly global climate change. The interspecific interactions within or between trophic levels has also a crucial impact on species range shifts (Lavergne *et al*., 2010). However, species distribution is often influenced through species-specific physiological thresholds of temperature and precipitation tolerance (Hoffman 1997). The shift could be either pole wards or towards elevation (Chen et al., 2011; Lenoir et al., 2008; Parmesan 2006; Walther et al., 2002). Longterm monitoring studies revealed that changes in community plants composition might be attributed to climate change (Brooker 2010). Their existence, however, depends on their ability to respond to environmental changes individually or by the emergent properties they developed. Several external factors could also cause either upward or downward shifts (Brooker 2010; Grabherr *et al.*, 1994; Kullman 2001; Sturm et al., 2001; Walther et al., 2005) of species. Hughes (2000) point out that an increase of annual temperature of 3°C corresponds to a shift of approximately 300–400 km in latitude (in the temperate zone) or 500 m in elevation. Nonetheless, not all species respond similarly to climate change (Walther 2010).

Out of the 99 species in research of species range shift, Parmesan and Yohe (2003) reported 80% of them showed shifts in range distribution. The average pole ward (latitude) and upward (elevation) shift was 6.1 ± 2.4 km and 6.1m decade^{-1} respectively. Chen et al. (2011), however, reported 17.6km and 12.2m decade^{-1} latitudinal and elevation range shift respectively. Research in Southern California Santa Rosa Mountains (Kelly and Goulden 2008) found that the distribution of the dominant species rose by an average altitude of approximately 65m. Except the one species, *Agave deserti*, which shows a shift towards lower elevation by about 50m; the remaining species showed up ward shift by about 28-142m. Moreover, Wardle and Coleman (1992) recorded the advancement of treeline towards higher altitude in New Zealand. Grabherr *et al*. (1992) showed that the alpine plants in Europe shifted towards higher altitude by about 1-4m per decade due to global warming.

Lenoir et al. (2008) studied the upward shift of an assemblage of 171 plant species along elevation gradient against climate change. They reported most of the species, one third or 118/171, shifted towards higher elevation with an average elevation of 29.4 ± 10.9m per decade. Whereas, 53/171 species shifted their range to lower elevation. Moreover, they revealed that species that shifted the most are mountainous species, which have faster life history traits (shorter life cycle, faster maturation, and smaller sizes at maturity) than do species showing a reduced shift (trees and shrubs), as compared with ubiquitous species (Cannone and Pignatti 2014; Grabherr *et al.*, 1994;Pauli et al., 2007) and increased their species composition. Even though it is very challenging to precisely explain observed upward shifts of plant species, it could be perhaps from either upward migration through dispersal of species from lower elevation belts and/or by resident species shifting upward Breshears *et al*. (2008); range filling (without any upward shift) performed by species dispersing from existing neighbor communities within the same elevation belt (Cannone and Pignatti 2014); or because of extinctions at low elevations or colonization at high elevations either at the margins of or within the species' range (Wilson and Gutiérrez 2012). Krosby *et al.* (2015) reported the species range shift overlap induced due to climate change. Consequently, species range shifts and the newly established communities could have an impact on the intra- and interspecific interactions that imply consequences for the functioning of ecosystems (Walther 2010). Several factors such as habitat destruction, agricultural expansion, urbanization and etc. may also influence species range shifts. Due to this reason organisms, may be forced to colonize a new area in which anthropogenic perturbation is minimal. Grytnes *et al*. (2014) showed that climate warming is not the dominant driving force for species range shift and have no significant relationships.

Unlike the researches on species response to climate change, literatures on plant community response to climate change are not extensive. Study on community response to climate in Vermon, USA by Pucko *et al*. (2011) revealed that species and community response don't follow constant pattern rather it is complex and tend to be idiosyncratic, which indicates communities would become increasingly divergent as the magnitude of climate change increase.

Considering biological diversity at broad scale level, biome integrity can be affected by changes in vegetation formations due to climate change (Bellard *et al*., 2012). Shifting dominances of species within communities could happen, but also to the formation of non-analogue communities, where existing species will co-occur, but in new combinations (Walther 2010). The Millennium Ecosystem Assessment forecasts there may be irreversible shifts for 5–20% of Earths terrestrial ecosystems, in particular cool conifer forests, tundra, scrubland, savannahs and boreal forest (Sala *et al*., 2005; Afunmilayo, 2016). The Sahel, for example, changed from tropical forest to grassland and then to dessert within few thousand years (Kropelin *et al*., 2008). Lapola *et al*. (2009) predicted large portion of the world's largest remnant forest, Amazonian rainforest, could be converted to tropical savannah. Alpine and boreal forests are expected to expand northwards and shift their tree lines upwards at the expense of low stature tundra and alpine communities (Alo and Wang 2008). Grimm et al. (2013) reported the movement and growth of trees into adjacent Tundra.

According to Briggs (2009) special habitat requirement, invading the already occupied territory, co-evolved mutualism (pollinators and dispersal agents), and speed and rate of dispersal play a significant role in species range shift. He also stressed that the whole plant communities don't migrate; rather the migrant plant species will establish new plant community. This implies the present plant communities may dissociate as a result of plant migration in response to climate change.

Thus, species range shift and resulting community reorganizations have considerable impacts on the way species interact, and, through trophic interactions, imply consequences for the functioning of ecosystems. Hence, community reorganization will not only lead to a reshuffling of existing species; in times of global exchange of organisms but also 'new' species will arrive, mix in and compose novel assemblages, and thus contribute to modified ecological networks and alter ecosystem processes (Walther 2010).

4. CHANGE IN SIZE

Living organisms and communities respond to climate change in different ways. Responding through phenology and range shifts were discussed in the previous sections. In addition to the previously discussed responses, change in plant size is also other mechanism exhibited in by several taxon (Morris et al., 2008; Sheridan and Bickford 2011). Climate change, as a result of increasing temperature, is influencing several living organisms, including plants, to shrink their size (Sheridan and Bickford 2011).

Studies revealed that plant species both under controlled treatment of higher temperature and drought showed reduced their size (Kim et al., 2007; Parolin et al., 2010). It is due to the failure to control the ever high temperature, and others, if any, plants size is shrinking these days (Barber et al., 2000). Nevertheless, phenotypic plasticity plays a role in shifting size (Franks et al., 2013; Sheridan and Bickford 2011). Though it is predicted that smaller sized plants could dominate the terrestrial ecosystems, its ultimate consequences is not yet fully understood (Sheridan and Bickford 2011).

5. PHENOTYPIC PLASTIC RESPONSES

Besides the phenology, size shrinkage, and species range shift; plants also respond through a process called phenotypic plasticity (Anderson et al., 2012; Nicotra *et al.*, 2010) in which range of phenotypes a single genotype can express as a function of its environment without changing their genetic constitution (Gienapp *et al.*, 2008). This phenomenon, usually, evolves when the organisms face several abiotic and biotic conditions in their life time (Baythavong 2011). They can also adapt to the changes genetically through the process of evolution (Gienapp *et al.*, 2008). It is, however, microevolution in which macroevolution was reported nowhere else.

Phenotypic plasticity could be, of course, adaptive or non-adaptive (Ford-Lloyd et al., 2014). If population can change genetically to adapt the ever changing climate, there could be a possibility of reducing risk of extinction (Sgro *et al.*, 2011; Spielman *et al.*, 2004). However, accurate measurement of plasticity is very challenging (Kingsolver et al., 2012) because the genetic underpinnings of most traits are not fully known yet (Anderson et al., 2014).

A phenotypic plasticity research on three species of *Patagonian* steppe grasses by Couso and Ferna´ndez (2012) revealed that the species which entertain more phenotypic plasticity the better to tolerate drought. Some authors, however, argue that the phenomenon of phenotypic plasticity doesn't happen in many species (Merila and Hendry 2014).

Briggs (2009) point out that under conditions of continuing climate change, it is highly likely that populations of species will reach the limits of their development adaptability and phenotypic plasticity, and organisms will be subjected to directional selection. ''If a species is evolving in relation to climate at a time when major changes are occurring, then, in the simplest hypothesis, it might be expected to remain in the same geographical area without migrating'' (Bradshaw and McNeilly 1991). This is analogous to species shift their range if they would become extinct if they stay in their original habitat. In his explicit review Briggs (2009) point out there is a micro evolutionary response against climate change.

Bradshaw and McNeilly (1991) argued that: *"Most species, but perhaps not all, are unable to evolve, or evolve sufficiently, to cope with all aspects of the climate change. Although species may be able to evolve to some extent, they are certainly not able to evolve enough, to all the different aspects, to be able to remain in their original habitats as climate changes; they will be forced to migrate. Then, if geographical features prevent migration, they will become extinct, for example as Tsuga and Pterocaryaare in Europe".*

Donnelly et al. (2011) argued that adaptation to climate change is heritable. Researches on garden plants in Europe, for example *Populus*, revealed that the majority of the phenotypic variance in the phenology of the plants in study could be explained by heritability (Bradshaw and Stettler 1995). However, solid evidences are still lacking whether the phenological shifts are due to phenotypic plasticity or result of underlying genetic variability.

6. SPECIES EXTINCTION

Man-induced climate change, which could be considered as the sixth species mass extinction, is one of the major threats to biological diversity (Barnosky *et al.*, 2011; Hannah 2011; MEA 2005). Even though researches on climate-induced species extinction are scanty, its impact could be more severe than habitat destruction (Bellard *et al.*, 2012) which is the cause for the extinction of above 90% species assessed by IUCN Red List of Species. Thomas et al. (2004) claimed that out of the estimated 5 million terrestrial species, 18-34% species are at risk of extinction caused by climate change.

Thus, if species and communities are unable to withstand the ever changing climate through the previously mentioned ways and; we are unable to mitigate climate change; species extinction would be the worst in our history. The worst thing is the speed of climate change is faster than the response of species and communities to withstand the impact of climate change (Bellard *et al.*, 2012).

7. PERSONAL REFLECTION ON PLANT SPECIES RANGE SHIFT AND CONSERVATION PLANNING AND PRIORITIZING

It has been discussed previously that species shift their ranges if they fail to adapt in their native habitat. Hence, following the traditional (species level and site/habitat level) conservation approaches alone won't be successful. Now a day, there are several species distribution models (SDMs) which can predict the magnitude and direction of species range shift. Thus, conserving species where they currently exist is good; thinking conservation approaches where species will be in the future, as well as connections in the landscape between the two, however, would be the better.

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