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Plant species respond to environmental change remaining within the modified climate by tolerance or adaptation and migrating or a combination of both.

Mesfin Belete Hailemariam*

Department of Biology, Wolkite University, Ethiopia and Department of Plant Biology and Biodiversity Management, Addis Ababa University, Ethiopia

Abstract

Climate is an important determinant factor that controls the geographic distributions of a plant species more than any other factors. Climate is changed when the average long-term weather patterns of a region are altered for an extended period, typically decades or longer. The cause of climate change can be categorized as natural processes and human activities that increased the level of emission of greenhouse gases into the atmosphere, mainly carbon dioxide. Plant species respond to environmental change remaining within the modified climate by tolerance or adaptation and migrating or a combination of both. The major response of plant species to climate change is: phenology (time), phenotypic plasticity, gene flow, species range shift (migration). Seed dispersal is essential for allowing plant migration to reach specific habitats that are favorable for survival and determining the migration ability of a specific plant species. The degree of movement of a species to favourable climatic conditions depends on its potential migration rate. The potential migration rate of a species is determined by seed dispersal capacity of the species and the population growth rate of plants in newly established populations, the seed size and competition also determine the potential migration rates of a species.

Keywords: Adaptation, Environmental Change; Gene Flow; Migration; Phenotypic Plasticity; Range Shift; Seed Dispersal.

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Introduction

Plant Species occupy a unique geographic range where the members of their populations live and reproduce. Different species of plants require different factors to survive and have specific limits of tolerance to factors that affect their survival or reproductive success [1]. The plant communities and their component species are exposed to changes in the environment [2]. Climate is important determinant factors that control the geographic distributions of a species more than any other factors such as local environmental conditions including micrometeorology, soil nutrient status, pH, water-holding capacity, and the physical elements of aspect or slope and influences how species live, reproduce and the structure of the habitats, communities, and ecosystems [3-5].

The range of species and their composition has been changing due to several factors, mainly global climate change. The inter-specific interactions within or between trophic levels has also a crucial impact on species range shifts [6]. Other complicated factors that can cause range shifts (migration) in plants are atmospheric nitrogen deposition, grazing changes, anthropogenic dispersal, disease, biotic interactions (invasive species), general eutrophication, and many forms of land-use change [7]. In arctic biomes or ecosystems, climate change is more likely to affect biodiversity than any of the other drivers [8; 5].

Climate is changed when the average long-term weather patterns of a region is altered for an extended period of time, typically decades or longer, hence it includes shifts in wind patterns, the average temperature or the amount of precipitation [9; 10]. Climate changes are a major concern in many areas of socio--economic activities, such as agriculture, forestry, etc., and are a major threat for biodiversity and ecosystem function [11]. The cause of climate change can be categorized as natural processes (such as volcanic eruptions, variations in Earth's orbit or changes in the sun's intensity) and human activities (like the burning of fossil fuels such as oil and coal, industrial development, agriculture, deforestation, etc) which increased the level of emission of greenhouse gases in to the atmosphere [12; 13; 8], mainly carbon dioxide. Since the beginning of industrial revolution, the global atmospheric carbon dioxide concentration increased from 270 to 401 μL L−1 and average global temperatures has risen by 0.85°C [14]. And also, the last 30 years were the warmest decades in 1,400 years [13]. According to the greenhouse gas scenarios [14], at the end of this century CO_2 is expected to reach at least 700 μL L−1 and global temperatures are projected to raise by 4°C or more. This paper aimed to review researches on the impacts of environmental change on the distribution of plant species and the management options for adaptation to climate change (Figure 1).

Plants response to climate changes

Climate change controls the distribution of ecosystems, species range, and processes on the earth [15]. The evidence obtained from palynology and fossil records shows that plant species respond to environmental change remaining within the modified climate by tolerance or adaptation and migrating to track suitable conditions, or most likely a combination of both [16]. The major response of plant species to climate change is phenology (time), phenotypic plasticity, gene flow, species range shift (migration) (Figure 2).

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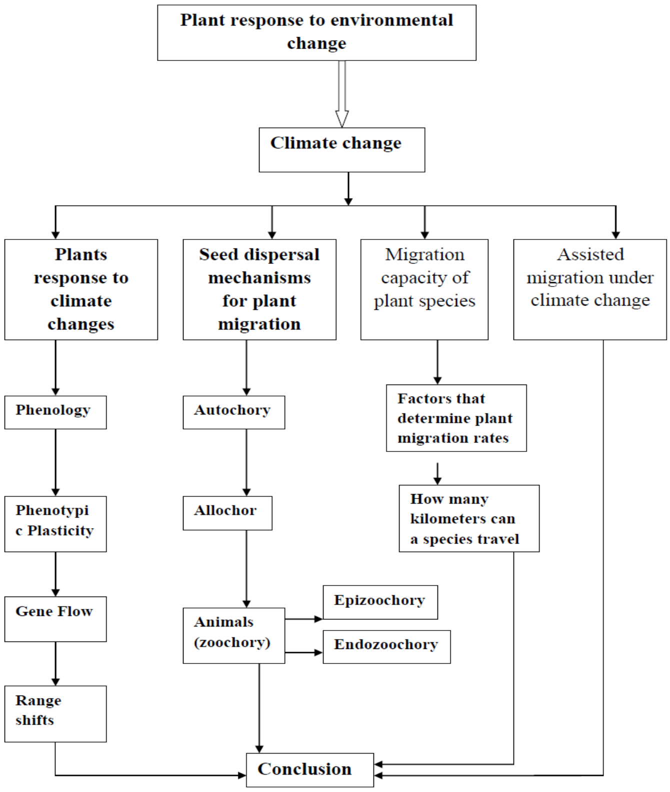

Figure 1. *Conceptual flow chart showing the major focus areas of the review.*

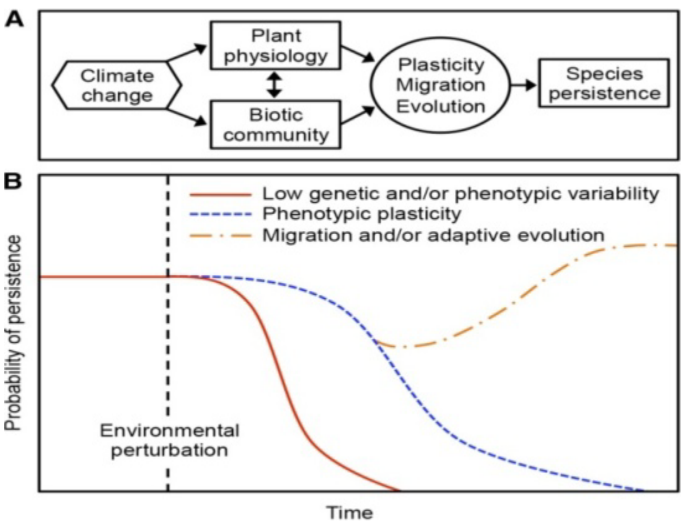

Figure 2. *Species response to climate change*

A. Shows the probability that a given species persists with climate change (both in the past and future) is influenced by the degree of phenotypic plasticity, the ability of populations to migrate, and the potential for populations to evolve traits that are adaptive in the original environment [13].

B. Plant populations with low genetic and/or phenotypic variability are unlikely to persist (red line). Phenotypic plasticity can facilitate the tolerance of environmental change over the short term (blue line). Migration to a more favorable environment and/or the evolution of adaptive traits (including greater plasticity) can facilitate long-term responses to environmental change (orange line) [13].

Phenology

*Phenology*is the seasonal pattern of activities, life histories of an organism. Also it refers to recurring, seasonal plant and animal life cycle stages, such as leafing and flowering, maturation of agricultural plants, the emergence of insects, and migration of birds [17]. Shifts in the timing of phenological events serve as powerful biological indicators of global climate change [18], and the phenological variation among species is vital in avoiding competition, which could help them respond better to climate change [19]. And also, phenological shift increases the primary productivity of an ecosystem, since longer growing seasons are more productive than shorter growing seasons [20].

Phenotypic Plasticity

Phenotypic Plasticity refers to the changes in an organism's behavior, morphology, and physiology in response to environmental change [21; 22]. It is a fundamental mechanism by which species respond to a changing environment [14]. Plasticity can facilitate evolution by alleviating the immediate selection pressures imposed by climate change, providing more time for evolutionary responses through genetic assimilation [23].

Gene Flow

Gene Flow describes the movement of genetic traits within and among populations, as individual animals or plants breed [24]. Plant populations are connected over spatial scales by pollen and seed dispersal, and gene flow can expand genetic variation, reduce inbreeding, and facilitate evolutionary responses to selection [14]. He describes that under climate change; gene flows introduce pre-adapted alleles to warm conditions and also can restrict evolutionary responses to climate change by introducing maladapted alleles into populations that are already lagging in their adaptive responses to changing.

Range shifts

Range shifts Plant species are capable of migrating to newly suitable sites before they become extinct on their original sites. Because of climate changes, species may no longer be adapted to the set of environmental conditions in a given region and fall outside its climatic niche [25]. At a global scale, the temperature increased by 0.740C, with a 1.10C increase in North America over the last five decades, and identified as a major cause of climate change which leads to a systematic change in the geographic distribution of species [26]. As a response to ongoing climate change, many species begin to shift their distributions towards the pole (latitudes) and higher elevations and mountain environments are predicted to experience rapid climatic changes [22; 26-28]. Because of this, there is a greater risk of habitat loss and local extinctions for species at high elevations compared to species at lower elevations [29]. The paleo-ecological record shows that climate change causes a dramatic shift in alpine plants or forest species. Therefore, migration is a strategy used to adjust to changing environments, and the migration of plant species limited by dispersal ability [31]. Seed dispersal is essential for plant migration to reach specific habitats that are favorable for survival [32], and it determining the migration ability of a specific plant species [31].

Seed dispersal mechanisms for plant migration

The movement of seeds away from their parent plant is called seed dispersal. Migration of plant species (directional shift), is a complex process determined by dispersal potentials, fecundity, population establishment, population growth, landscape structure, and the availability of suitable habitat [28]. Plants populations migrate in response to climate change rely on dispersal capabilities and their ability to establish a new site. Migration is a major autogenic adaptive response of wild species to ongoing and future climate change [33]. Unlike animals, plants have very limited mobility to search for a better home and consequently rely upon a variety of modes of dispersal vectors. There are two broad categories of seed dispersal such as autochory and allochory (dispersal through external means).

Autochory

Autochory is the dispersal of seeds without any external vectors, this limits the distance they can disperse their seed [34]. This can be achieved through Gravity (Barochory) where heavy fruits usually fall from the tree. After the fruits fall, a secondary agent, like animal or water, may disperse it. Seeds dispersed by gravity are coconuts, calabash, passion fruit, apples, hedychium, cerinthe, commelina, canna, etc [34], and Ballistic (Ballochory) the seed are forcefully ejected by explosive dehiscence of the fruit and which are powerful enough to throw the seed up to 100 meters. This explosion happens due to the Sun and the seed pod starts drying out due to heat. This creates tension along the walls of the pod or turgor pressure within the fruit. Thus, the pod splits open, and the seeds are violently ejected in the air [34].

Allochory

Allochory refers to any types of seed dispersal where a vector or secondary agent is used to disperse seeds. These vectors include, wind (anemochory) disperse small, light, hairy, and feathery seeds. Some seed pods face upwards; as the wind pushes them, the seeds flow away. Plants seeds that are dispersed by winds are dandelions, swan plants, cottonwood tree, hornbeam, ash, cattail, puya, tecoma, willow herb, etc [34].

The other agents are water (hydrochory), the seeds or fruits must be waterproof, light, and hollow to float on water. Seeds can travel extremely long distances, thousands of kilometers in water. Such as Coconuts, mangroves, foxglove, brooklime, yellow water lily, and water mint.

Animals (zoochory) are the most common dispersal agent. They can disperse seeds in two ways: epizoochory and endozoochory. Epizoochory is the transport of seed on the external of vertebrate animals. Some seeds stick to the fur of animals and are carried to new areas. The seed may have a variety of adaptations for dispersal, including adhesive mucus, hooks, spines, barbs, and projections or hairs which help them adhere to the animal [35;34], eg. *Trifolium Angustifolium*, adheres to animal fur using stiff hairs covering the seed [36]. This form of seed dispersal has been implicated in rapid plant migration and the spread of invasive species [36; 34]. Endozoochory is the dispersal of seeds internally or via ingestion by vertebrate animals (mostly birds and mammals). Animals are attracted to fleshy, edible, nutritious fruit and consume them [37], and then, the seeds are defecated from their bodies. Among the modes of long-distance dispersal of plants anemochory (wind dispersal), and zoochory (animal dispersal) are the most common [38; 34].

Migration capacity of plant species

Factors that determine plant migration rates

The migration rates of species are limited and depend on inter-linked effects of climate, inter-specific competition, and landscape fragmentation [39]. Migration of species is the most common biotic response to climate change. The degree of movement of a species to favorable climatic conditions depends on its potential migration rate. The potential migration rate of a species is determined by two main factors, the seed dispersal capacity of the species and the population growth rate of plants in newly established populations [40]. The seed size also determines the potential migration rates indicating small-seeded species have superior migration ability because they are more efficient at dispersal than large-seeded species with the same dispersal mode [31].

The competition also affects the rate of migration; migration rates decrease with increasing numbers of competing species [5]. The migration rates of early successional species are about 10 times faster than mid- to late-successional species [39], because of the rapid growth rates, large amounts of seed, and long seed dispersal distances of early successional species. Therefore early-successional species colonize new potentially suitable habitats much faster due to their lower migration limitation [39].

How many kilometers can species travel?

Plant's fitness and survival depend on Long-Distance Seed Dispersal (LDD), with certain environmental factors [41]. A driving feature for LDD has increased plant fitness by decreasing neighboring plant competition for offspring and it is evidence for rapid plant migration [36]. Large jumps (long-distance dispersal) involve the selection of seeds by birds, bats, wind, resin-collecting stingless bees, vertebrates, and large terrestrial mammals which can transport seeds tens of kilometers or more before defecating, regurgitating, or dropping [42;43]. One km is taken as the threshold (minimum) distance at which a plant can disperse its seeds and it is counted as LDD [41], however, others consider a seed dispersal event to be ''long-distance'' if it is over 100 m and relatively small spatial scales is less than 100 m [44]. Sticky seeds, or those with hooks or barbs, may remain attached to a bird or mammal for long periods, and small seeds may be carried in mud on the feet of animals [38].

In eastern North America, the migration velocities are as high as a kilometer a year. A species can track increasing temperatures by shifting its range upwards, pole-wards, or a combination of both [26]. According to [45], the increase in the mean annual temperature of 0.70c in Australia shows an average decrease of 0.50c per 100m along with altitudinal increase, this causes a shift of 8 m to 10m per decade to altitudinal vegetation. According to [46], the average poleward (latitude) and upward (altitudinal) range shift of a species were reported to be 17.6 km latitudinal and 12.2m elevational per decade. The distribution of nine species out of the widely distributed 10 species in the year from 1977 to 2006/2007 indicates that an average altitudinal shift of 64.7 m, ± 33.8 m [47]. They showed that many species including alpine herbs, birds, and butterflies are found an average poleward shift of 6.1 km per decade. According to [47] report, from the total of 171 species, 118 moved towards the higher elevation and 53 species shifted their range to lower elevation, most are shifting upward in response to climate change.

In temperate zones, an increase in the annual temperature of 30C change cause a shift of approximately 300 km to 400 km in latitude and/or 500 m in elevation [4]. A recent meta-analysis of 23 studies estimating shifts in latitude and 31 estimating shifts in elevation reported an overall migration rate of 16.9 km poleward and 11.0 m upward per decade. Seeds of many temperate forest herbs, including Trillium grandiflorum, are dispersed primarily by ants and carry the seeds 0 m to 2 m and rarely 30 m to 40 m from mother plants. Deer may disperse trillium seeds up to 3.8 km, but also negative effects of herbivory [40]. The distribution model of Pinus pinaster moving across fynbos landscapes in South Africa suggests that 160m per year and maximum spread rates of over 750m per year. This long-distance dispersal is a key to understanding rapid plant migration [43].

The research was done in California, Oregon, and Washington of USA indicates that the mean elevation and latitude range of seedling distribution of most species was both higher than and north of the mean of the range of mature trees, in response to a warming climate. The seedling distribution of a species is higher and north of the mature trees. Study [26] indicates that the average mean seedlings distribution of almost all species was higher (26.58 m) and north (11.22 km) of mature trees, however seedlings of one species distributed in a decrease elevation and south of the latitude with a small the differences [26]. The migration rates are estimated to increase in the order of 0.1 km to 1 km per year for temperate mixed forests, because of the doubling of atmospheric CO2 concentrations over the next century. This leads to a shift of approximately 2000 km to 20000 km for 21 000 y [40]. The mean annual temperature range of seedlings was 0.12°C which is lower than that of the tree species, and the mean annual temperature range of seedlings was colder than that of the range of trees. Thus only 4 species out of 46 species were shifted towards warmer areas [26].

Assisted migration in species conservation under climate change

Assisted migration is an important means when the rates of species' range shifts are too slow relative to the expected rates of climate change and are not able to cross natural and human-created barriers. Therefore, assisted migration increases dispersal by actively moving species from their current locations to climatically suitable regions [27]. Assisted migration is the intentional transfer of flora or fauna to a new region in response to climatic change. It avoids species extinction from the harmful effects of climate change [48]. Species that are endemic to the summits of single mountain ranges are projected to become extinct. Therefore, increasing the dispersal capacity of endangered species might represent the most effective climate change adaptation strategy to reduce extinction rates [27].

People serve as a kind of super dispersal mechanism to avoid the effect of climate change on native species by moving seed longer distances (thousands of kilometers) than they could travel on their own [43;49]. Assisted migration remains controversial those in favour of assisted migration argue that the risks are limited if assisted species movements are well planned and the right species into the right locations. For example, the introduction of an ecologically equivalent species to replace an extinct one [3]. However, the fear is that translocated species become 'invasive' in their new ranges [27]. Invasions by alien organisms and diseases resulted in the extinction of native species or huge loss of ecosystem services. For example, in the United States, invasions of non-native plants, animals, and microbes are thought to be responsible for the 42% decline of native species now listed as endangered or threatened [50]. The alien Eurasian cheatgrass (Bromus tectorum) can expand into western North America, occupies a range of about 200,000 square kilometers within the last decade of the 40 y invasion [42]. Therefore, translocation of a species beyond their native range is an option when traditional strategies are insufficient.

Conclusion

Forest This paper provides information on the impact of environmental changes on the distribution of plant species. It provides the major plant responses to climate change and contributes to the management options for adaptation to climate changes. This climatic information helps to understand the climatic factors and to predict the future distribution range of a particular species. There is a need for a policy to support climate change mitigation. This is the responsibility of the national and local governments, communities, private sectors, and international agreements for supporting adaptation. More active management is required to maintain particularly forests in conservation reserves. Therefore it is necessary to strengthen the relationship between climate science, forest research, forest managers, and the community.

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***Correspondence to:**

MesfinBelete
Department of Biology
Wolkite University
Ethiopia
Tel:0911993690
E-mail:mesfinbelete90@yahoo.com