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Impact of Climate Change on Arctic Vegetation: A Review

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ABSTRACT

The climate change and global warming due to various anthropogenic and natural factors disturbs the ecosystem structure and functions. The unstoppable emissions of GHGs (greenhouse gases) has resulted alteration in vegetations types, compositions that affects overall biodiversity and related ecosystem services. Arctic vegetations maintain ecosystem structure and processes in the temperate and cold regions of the world. These vegetations comprise diversified flora and fauna that maintain ecological stability by providing tangible and intangible ecosystem services. However, changing climates and extreme weather affects overall parameters of arctic vegetations which is major concern today. Change in plant communities, phonological, reproductive changes along with vegetational shifting are peculiar impacts that faces by climate change and global warming phenomenon. The impact of climate change includes soil health, quality, fertility, SOC (soil organic carbon) pools, sequestration rate, rhizosphere biology, nutrient use efficiency, resource availability and nutrient cycling processes, etc. In lieu of above, this paper gives a full insight about arctic vegetations, it origin, evolutions and biodiversity in the world. Impact of climate change on various vegetational attributes, parameters and soils are also discussed in this paper.

Keywords: *Arctic vegetation, climate change, GHGs, SOC pools, phenology, nutrient cycling, vegetational attributes.*

INTRODUCTION

Vegetation structure, composition and diversity are varied as per varying soil quality, topography and changing climatic regimes. Changing climate and extreme weather affects vegetation attributes and dynamics. Temperate zone including arctic regions comprises peculiar vegetation types that play an important role in ecosystem structure and services. Arctic vegetation comprises different life forms of floral composition along with fauna that enhance biodiversity which intensify ecosystem services in both tangible and intangible ways. But, the extreme global warming accelerate the changes in the vegetation cover through increased life span, thaw depth and variable snow regimes (IPCC, 2013).Nearly half (50%) of the world's soil stored carbon in the permafrost is confined in high latitudes; which is constantly at risk of loss with increase temperature (van Gestel et al., 2018). Consequently, the changes in inputs (such as carbon and nutrient) in tundra soils vegetation may have an influence at global level. For instance, carbon storage above the ground, nutrients cycling and organic matter decomposition rates and albedo could be due to changes in the composition of species(Callaghan et al., 2004), possibly fluctuating the total climate-based responses (Pearson et al., 2013). Tropical interactions may also can also be hampered with shifting vegetations (Gauthier et al., 2013) as a result, the provision of natural resources and other benefits such as cultural purposes needed by wildlife populations and human inhabitants in the Arctic regions could be severely affected (Stern and Gaden, 2015).

The potential increased in carbon dioxide (CO_2) concentrations in the atmosphere leads to the corresponding increase in plant"s biomass production through photosynthesis. Subsequently, the arctic vegetation production would also be increased but, it is expected that the grouping of species in the communities of plants will be altered. As such, this proved that the degree of responses to environmental parameters including nutrients availability and temperature varies depending on the plant species. Hence, the theory of "survival of the fittest" occurred, where the adapted species would become the dominant species than the less adaptable species. As climate changes, how will terrestrial vegetation respond? As the vegetation cover solitary influence the fortunes of most hydrological, biogeochemical as well as economic cycles, this query is essential to the science of climate change but then, exceptionally challenging to discourse. This has been a tangible issue in the Arctic region in particular, where global temperature change is most critical (IPCC ,2007) in addition, the response to hydrologic, carbon and energy cycles for the earth system have been significantly impacted.

The extent of Arctic Sea ice as reported by the United States National Aeronautics and Space Agency (NASA), is continuously decreasing per decades by 12.8 percent since 1979; where the lowest level of the Arctic Sea ice was recorded in2012 (NASAJPL, 2018). This is likely to influence the lives of the inhabitants of around 1.5 million and distribution of the Arctic biodiversity in the region (Sinha and Gupta, 2014).

The progress of this scenario as reported by scientists may produce „Arctic-paradox‟ which will only worsen the condition: the next step due to climate change impact is that, the unreachable on-renewable resources will be extracted easily; all these actions will in turn facilitate the so-called global warming (Chaturvedi, 2013). Currently, the eight (8) Arctic countries, comprising the Arctic Council includes; "Norway, Sweden, Finland, Iceland, Russia, Canada, Denmark, and the United States" including the Council‟s thirteen (13) Observer States are the major participants in widening the Arctic region. The geopolitical, economic potential as well as strategic nature are the key facts explored by these countries in the Arctic region. In view of Above this paper discussed comprehensively about arctic biodiversity its origin and evolutions along with climate change impacts on different parameters of varying vegetations in the world.

ARCTIC VEGETATIONS

The tundra, polar desert as well as northern part of the boreal forest are the zones covered by arctic vegetation. The extreme northern zone that dominates the high arctic region is the polar desert, often characterized by bare ground of open patches and total absence of woody vegetation. Despite the fact that, the vegetation of the polar desert is quite scant, some species that are rarely found in this zone includes musk ox along with small sub-species of caribou /reindeer. Tundra is characterized by low shrub vegetation (Bjorkman et al., 2020; Cuyler et al., 2020).

Species adapted to Arctic region thrives in the temperature just below or above 0°C, in order to complete biological processes, like seed propagation, germination and growth. This adaptation give the species added advantage (adaptation) compared to heat-loving species that dominate the southern province. In more temperate regions, this competitive advantage will turn to be invalid as the migration of southern species will commenced towards the northwards and overwhelm the natural arctic species. Similarly, this happened where equal trends is observed in the mainland Norway after the last ice age when the ice withdrew. There is a blurred picture for Svalbard. As per scientific observations, the varying plant species have been transferred and migrated through wind dispersal from Greenland and Russian countries onwards the last ice age. Mountain avens and dwarf birch were dispersed through wind whereas crowberry and bilberry through bird dispersal.

Arctic Biodiversity: A Historical Development

In an effort to comprehend biodiversity in the Arctic and the basis for the changes of circumpolar vegetation, a meticulous strategies for the connection between the detail structure and conformation of Arctic vegetation and its environment needs to be applied for of the Arctic vegetation and its linkage with the environment which is also a milestone for the studies of remote sensing (Myers-Smith et al., 2015).

The International Biological Program (IBP) Tundra Biome stimulated Arctic vegetation research between 1967 and 1974 (Bliss et al., 1981) that synthesized various hypothesis in the year 1990s.In recent time, the Conservation of Arctic Flora and Fauna (CAFF)of the flora Group made a tremendous improvement in the sight of circumpolar Arctic vegetation toward the integrated approach. The proposed Circumpolar Arctic Vegetation Map (CAVM) at the International Arctic Workshop on Taxonomy of Arctic Vegetation in Boulder (1992), CO(Walker et al., 1994), was successfully accomplished in 2003.

The map provided a structure for the Arctic Biodiversity Assessment (ABA), that encompassed three (3) circumpolar vegetation-related syntheses dedicated to florae, fungi (Dahlberg et al., 2013), as well as terrestrial environments. Diverse forms of organisms are also peculiar feather of arctic climate that supports a better biological processes and ecosystem structure which is shown in Figure 1.

As per figure, the insect class occupied a maximum numbers (3000) followed by several other organisms in the order of Fungi (2500)> Lichens (2000)> flowering plants (1735)> Algae (1200)> Mites (700) > Mosses (600)> Springtails (400)> spiders (300)> Liverworts (250)> birds (240)> mammals (75)> ferns (62) and least value (12) in conifers, respectively (CAFF, 2001; ACIA, 2005).

Origin, History and Evolution

One of the most important point of concern is how the Arctic and alpine plants got originated historically. Matthews and Ovenden (1990) reported that, certain plants were known to be present in the Arctic not less than 3mya since the fossil record. But then, little about the composition and nature of the floras‟ founding stocks together with their origin were known.

To identified where these Arctic and alpine floras occurred at variable times all over the late-Tertiary and Quaternary periods, fossil proof is the basic. Most of this proof has been reviewed, of which the information acquired from the last ice-age plus present interglacial constitute the mainstream (Birks, 2008). Increase in genetic diversity attributed to the postglacial colonization in central Europe of the present population of species of trees due to differed genetic material from refugia at the Last Glacial Maximum (LGM), around the past 18,000 years sited in eastern, central and southern Europe (Petit et al., 2003).

It has long been the point of doubt and guessed by Phytogeographers as whether the arctic plant partially originated from the ancestral stocks and later strolled northwards from the high mountains to the southern Asia and North America during the late-Tertiary (Hultén, 1937; Tolmachev, 1960;Murray 1995), and from herbaceous and shrubby elements of the Tertiary arctic forests (TAFs) (Murray 1995), along with through evolution of locally taxa.

The significant point of concern from the present studies assumed that phylogeograhies among diverse arctic and alpine plants varies significantly, nonetheless having similar geographical distributions. In this scenario, variation between phylogeographic may possibly reveal, for example, variations of the species (modern or relatively age-old), variances in the properties of certain glaciations or inter glacial on series disintegration (because of chance or merit impacts), and transformations in breeding system and life historical characteristics which included generation times and varying dispersal methods.

Moreover, the northern refugium based evidence for Saxifraga opposite ifolia has been observed from the analysis of molecular phylogeographic and which was later validated by fossil based evidence (Abbott and Comes, 2004).

Indian Arctic Vegetation

On the name of Himalaya, India first arctic research station was “Himadri” (firstly inaugurated by Ministry of Earth Sciences on 2008) which is situated at Norway, Spitsbergen and Svalbard regions. This research station was located from 1200 km distance from the North Pole region (Jacob, 2013; Research Base "Himadri, 2010; MEA, 2018; Koshy, 2018).

India is a home of diverse flora and fauna, comprises diversified vegetations from north to south and east to west.

Vegetation structure, compositions and diversity are important vegetational attributes of tropical, arid and temperate including arctic or Polar Regions which is based on varying climatic regimes.

Temperate vegetation types includes Palearctic temperate coniferous forests, North-eastern Himalayan subalpine conifer forests, Palearctic montane grasslands and shrublands, Eastern Himalayan alpine shrub and meadows, Karakoram-West Tibetan Plateau alpine steppe, North-western Himalayan alpine shrub and meadows, Western Himalayan alpine shrub and meadows etc which are prevalent in various countries mostly in India.

Types of Palearctic vegetation in different countries including India are depicted in table 1.

Table1. *Palearctic vegetation in different countries including India*

Vegetation types	Descriptions	Prevalent Countries including India
North-eastern Himalayan subalpine conifer forests	This ecoregion is distributed throughout the eastern Himalayas elevation and south-east Tibetan Plateau regions.	It covered Bhutan, China and most parts of the Indian subcontinents.
Eastern Himalayan alpine shrub and meadows	This is generally montane grassland based ecoregion distributed throughout the eastern Himalayas consisting in between tree line andsnow line.	It covered Bhutan, China, Nepal, Myanmar and most parts of the Indian subcontinents.
Karakoram-West Tibetan Plateau alpine steppe	This is generally montane grassland and Shrublands based ecoregion distributed throughout the upper range of Himalayas	It covered China, Pakistan, Afghanistan and most parts of the Indian subcontinents.
Northwestern Himalayan alpine shrub and meadows	This is generally montane grassland and Shrublands based ecoregion distributed throughout the north-western Himalayas.	It covered China, Pakistan and most parts of the Indian subcontinents
Western Himalayan alpine shrub and meadows	This is generally montane grassland and Shrublands based ecoregion distributed throughout the western Himalayas and ranges from tree line to snow line.	Covered Nepal and Indian subcontinent

Ecosystem Services through Arctic Vegetations

The connection between nature and human welfare was fully understood from the concept of ecosystem services (ES). In view of the exponential increase in scientific literature on ES from 1990s (Droste et al., 2018).Typical example is the Arctic region, commonly referred to as the „refrigerator of the world‟, providing regulatory services on the global climate impacts together with its neighboured Antarctic region (Walker, 2007).

Arctic vegetations harbours diversified plants and their products which play important role in ecosystem services and management. As we know, ecosystem services flows in different ways such as regulatory, provision and cultural services etc that maintains soil-food- climate security along with environmental sustainability (Raj, 2019; Jhariya et al. 2019;Raj et al., 2020). Species like berries in arctic regions mostly delivering peculiar services as regulatory services comprises pollinations of berries plants by diversified pollinators that helps in promoting provision services by providing diversified nutritious food and fruits material which maintains food and nutritional security. Similarly, berries maintain social, cultural and economic values through cultural services and overall maintain indigenous and local values by intensifying ecosystem services of berries plant. Thus there is a great link exist among regulatory, provision and cultural services that make a foundations/pillars of overall ecosystem services which strengthen people’s health, wealth and climate security (Figure 2). Generally, increased in carbon sequestration in tundra presumes to be due to improved productivity of the terrestrial region. Though, energy-budget associated responses are described in the above complicate figure. Furthermore, the higher released of stored carbon to the atmosphere through increased decomposition rate was attributed due to the corresponding rise in atmospheric temperature, despite the fact that, an increase in leaf litter produced that often takes long period to decomposed in tundra may reduce these impacts (Cornelissen et al., 2007).

Climate Change Impacts on Arctic Vegetations

Climate change is ongoing burning issue that impacts on all biodiversity, ecosystem structure and their functions. The impact of climate change on arctic vegetations is discussed rigorously. Changing plant communities, compositions, diversity, phenology, reproductive biology and shifting of vegetations are peculiar impacts have been observed in arctic vegetations. That impacts not only affects vegetational health and productivity but also impacts on ecosystem services which disturb ecological balance.

Changes in Plant Communities

Certain plant species develop natural mechanisms to fight for limited resources such as sunlight, temperature and nutrients accessibility amidst of their competitors. Plants species such as (the Betula nana, dwarf birch) in the presence of herbs and grasses species to have increased vegetation in the Arctic region. Similar trends were also obtained from the research projects result of 13 different Arctic areas. The diversity of plant species is observed to be at a risk of decline in plant populations were woody vegetation dominates. This is because woody vegetation surpasses both herbs and grasses for sunlight and nutrients accessibility (Liu et al., 2018). It has been observed by some scientists that, the distribution of mosses and lichens are also negatively impacted in vegetation with extensive woody plants. Species with a wider distribution within the Arctic climate suppress the specially adapted plant species, consequently, resulting in an overall biodiversity reduction. The effect of diversity changes of species among the plant population may significantly affect the group of animals either directly (as source of their food and shelter) or indirectly (as habitats to their prey).

Phenological Changes

The Term „*Phenology*‟ simply refers to the period of occurrence of biological phenomena for a given period of time. For the plant perspective, the relevant times includes; the period of leaf formation, buds, flowers and seeds. Some plants start phenological developments as a response to earlier melting of snow. The change differs with other group of species. This change in phonological development peculiar to certain plant species may give others competitive advantage by changing climate. The Since the period of growing season in the Arctic is a limiting factor, the earlier the plants develop and produce seeds the high chances of that seeds to set before the autumn season (the onset of frost). Usually, the long term phonological changes influence the arrangement of plant communities (Suonan et al., 2019).

Reproduction

A positive correlation exists between plants reproductions with increasing temperature, the changes are more significant on high Arctic compared to lowland sub-Arctic region respectively. Similarly, warmer climate have been reported on several studies to have a slight or even no negative effects on reproduction of certain plant species. These differences among plant species in reproductive behavior can alter the composition of the plant populations as a magnitude of competitive relationship (Klady et al., 2011). For example, group of plant species such as; the glacier buttercup(*Ranunculusglacialis*), alpine mouse-ear (*Cerastium alpinum*) and purple saxifrage (Saxifraga oppositifolia) are slightly affected by warmer climate, while on the other side, the fertility of the specie-canescent whitlow grass (Drabacana)was observed to be reduced on exposure to high temperature. In the co-existence of the above two species, lose-out of specie-whitlow grass may occur due to competition.

Vegetation Shifting

Impacts of variation on vegetation in tundra could be extended to tropic levels and ultimately, to the societies of human (Weller et al., 2004).The plant fitness at the individual and population level in influenced by the reproductive success and as well the changes in plant phenology (Cleland et al., 2012) as a result, the tropics may became unfavourable for the pollinators due to gaps of resources (Preve´y et al., 2019), breeding birds (Boelman et al., 2015) as well as mammal animals (Hertel et al., 2017). It was reported from a study conducted at Zackenberg, Greenland that, shortening of flowering with temperature increase for certain periods results in concurrent reduction of flowers visits by insects (Høye et al., 2013). Berry-producing (Hertel et al., 2017) other plant products such as forage for wildlife (hunted or domestic) from tundra plants (Kerby and Post, 2013) which altogether served the cultural benefits for the Arctic people as important resources (Henry et al., 2012).An increased reproductive efficiency (such as seeds number, number of harvested fruits or seed bulk) was reported from 4-years experiment at 10 Arctic sites on a warmed experimental plots, although insignificant response were obtained (Arft et al., 1999). Another experiment on single-site studies on warmed plots also revealed an increased efficiency in reproduction (Klady et al., 2011).

Among the effects of climate warming is the melting of permafrost, receding of glaciers and disappearance of ice-sea in the Arctic (IPCC, 2007). In the same way, tree lines at mountainous areas are rising and species under existing alpine habitat are endangered. The current goal in field of ecology and conservation biology is the forecast of possible changes that will happen with distribution of chionophiles species, and thus, the structure of Arctic and alpine biota. Swift nature of climate warming is the major cause and modern among the other climatic fluctuations to have a negative impact on the history of Arctic and alpine biota (Abbott and Brochmann, 2003).

The impact of changes induced by climate is beneficial in some aspects to both local people (in terms of; food, fuel and culture) and their animals (in terms of habitat) in Arctic landscape. The influence of these changes can be seen in global climate and resources because of the impact of Arctic landscape at the global climate. In the same vain, the changes in Arctic landscape are still underway and expected to be much greater in a near future. Modification in plant vegetation such as taller plant, dense vegetation and the transformation of forest to Arctic tundra, and then from tundra to polar deserts is primarily due to the effects of change. In the Arctic region, the duration of these transformations fluctuates and in the current century, the changes are expected to be obvious because of the suitable soils and other favourable environmental conditions. However, in the absence of the above conditions, the changes may last longer than expected.

As the sea level rises, the vegetation also changes, the tundra area was projected to shrink to its lowest since last 21 000 years ago, unfavorably the area suitable for animals grazing and birds breeding rely on an open habitats of tundra and polar desert landscape. Besides the high tendency of some species to become extinct, as observed by highly widespread species are at high risk of sharp declining. With the dropped of world's temperature, Arcto-Tertiary forest has been replaced with present day Arctic plants in the past 3-4 million years towards the completion of Pliocene. However, the expansion and disintegrations of plants were observed in both alpines and arctic regions due to shorter warmer periods and glaciations during the Quarternary age since 1.8 mya (Abbott, 2008).

Arctic Soil

Soil is a very important resource harbors varying flora and fauna, stores essential nutrients, and helps in climate change mitigation through carbon sequestration process (Raj et al., 2019; Raj, 2020; Raj and Jhariya, 2020). Generally, the insufficient soil nutrients content in arctic ecosystems is due to dominance of organic matter in the thicker layer of permafrost. The rhizosphere from which plant obtained nutrient is narrow; as a result most plant species therefore would be deprived of sufficient nutrients. On the other extreme, an increased temperature due to global warming enhanced the rapid decomposition process of organic matter present in an Arctic soil. As a consequences, thicker soil with potential to release large quantity of plant nutrients (such as; N and P) will be form.

Because of the total stored carbon in the permafrost soils of tundra region (Crowther et al., 2016) along with mutual relation carbon storage and surrounding vegetation, cycling of local carbon and response to the global climate is largely due to the influence of vegetation change in the Arctic (Petrenko et al., 2016). For instance, better snow trapping during the winter, high insulation of underlying soils and increased soil temperature during winter are all correlated with height of plant and/or predominance of shrubs (Myers Smith and Hik, 2013), in addition with increased decomposition and depth of the active layer (Blok et al., 2016).

Result of an experiment revealed that soil insulation and energy fluxes functions was observed to be realized by group of plants called 'bryophytes', removal of the plant amplified the ground heat flux and the rate of evapotranspiration (Blok et al., 2011). Changes in the quantity and decomposition rate of litter are impacted because of the alteration in vegetation composition and carbon cycle (Callaghan et al., 2004).Further, globalCO_2 fluxes has been contributed to about 70% through litter decomposition (Raich and Potter, 1995). Proliferation of shrubs on a long period may reduce the decomposition rate of litter and eventually, increased the global warming due to high recalcitrant litter (Cornelissen et al., 2007). Indirect effect of changes in litter composition includes an increased carbon storage in the soil which in turn facilitate the changes of the microbial population (Christiansen et al., 2018) otherwise modifying the loads of tundra fuel. For instance, the soil carbon loss as a consequence of increased flammability could possibly be due to significant increased of shrubs from the inputs of woody litter (van Altena et al., 2012).

Conclusion

Because of the species-specific response of Arctic plant on changing climate, it is thus, difficult pinpoint precisely how these plants are affected by climate. Though, the composition of the species and plant populations are observed to be varying according to botanists. The decrease in the diversity of pteridophytes is due to the abundance of species such as (such as; willow and dwarf birch species) collectively called woody vegetation. In exactly what way the species rely often the vanishing plants stand affected is not fully understood. Nevertheless, the consequence will surely manifest over time. On the same line, species of insects that are also species-specific will further suffer in population reduction or may be rendered extinction in the worst scenario with diminishing plant species. The negative effect of climate change can be manifested to food chain links through loss of biodiversity

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