Chapter 4
Climate Change and Costal Plant Lives

Muhammad Noor, Naveed ur Rehman, Ajmal Jalil, Shah Fahad, Muhammad Adnan, Fazli Wahid, Shah Saud, and Shah Hassan

Abstract Climate represent the earth's atmosphere over a given region, defined by certain factors viz. temperature, air pressure, humidity, precipitation, sunlight, cloudiness, and winds. While, climate change is the earth's climate periodic modification brought as a result of atmospheric changes as well as atmosphere and other various geological, biological, geographic factors interaction between them within earth system. The atmosphere is like the dynamic fluid which is always in the continuous motion. The direction of motion and physical properties and its rate are stimulated by different factors, including the geographic position, solar radiation, ocean current, chemistry of atmosphere, continents geographic position, the location and orientation of mountain ranges, and vegetation growing on the land surface. Global sea-level rise is one of the major outcomes of global warming (12–22 cm occurred during the twentieth century), and several other climate models project an accelerated rate of about 0.18–0.59 m rise in global sea-level in coming decades. Such climatic changes have altered the marine ecosystem greatly.

Keywords Climate change · Global warming · Ecosystem · Costal plants

M. Noor (✉) · N. u. Rehman · A. Jalil
Department of Agriculture, Hazara University, Mansehra, Pakistan

S. Fahad
Hainan Key Laboratory For Sustaianable Utilization of Tropical Bioresource, College of Tropical Crops, Hainan University, Haikou, Hainan, China

Department of Agronomy, The University of Haripur, Haripur, Pakistan

Department of Agriculture, The University of Swabi, Swabi, Pakistan

M. Adnan · F. Wahid
Department of Agriculture, The University of Swabi, Swabi, Pakistan

S. Saud
College of Horticulture, Northeast Agricultural University, Harbin, China

S. Hassan
Department of Agricultural Extension Education and Communication, The University of Agriculture, Peshawar, Pakistan

S. Fahad et al. (eds.), *Environment, Climate, Plant and Vegetation Growth*,
https://doi.org/10.1007/978-3-030-49732-3_4

4.1 Climate

Climate is the condition of every day's weather about the period of thirty years of a specific geological position. It is usually measured by the different factors such as temperature variation, wind, pressure of atmosphere, rainfall, humidity, atmospheric particle count and other variable factors in a specific geological hemisphere for a long time (Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2016, 2017; Shah et al. 2013; Qamar et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). It is different from weather because the weather is the short-term condition in a given region of these variables. Climate of a specific region is due to the climate system which is composed of five basic components: Biosphere, lithosphere, hydrosphere, cryosphere and atmosphere. Different factors affect the climate of a location for example the latitude and altitude, as well as the water bodies nearby and their currents.

Temperature and precipitation are the two variables on the basis of which climate is classified.

The most frequently used classification scheme is the Köppen climate classification. In the study of climate change and diversity, Thornthwaite system mainly incorporates the evapotranspiration and the data of temperature along with precipitation rate, from 1940s.

The regional climate is mainly describe by the origin of air masses and for their study we have two very useful classification systems like the Spatial Synoptic and Bergeron Classification systems.

The study of ancient climates is called Paleoclimatology. Before the nineteenth century, climate observations are not directly available but paleoclimates have confirmed from different variables that are abiotic evidences such as the sediments found in the beds of ice cores and in the beds of lakes, and living or biotic such as coral and tree rings. These climatic models are the mathematical models of past, present and future climate. Climate change occurs by different factors over short and long timescales i.e. global warming, which results in redistributions. For example, the change in the mean annual temperature about 3 °C corresponds approximately 0.5 m in elevation or 187–248 Miles in latitude (in the temperate zone) shift in isotherms. Therefore in response to shifting climate zones, the species are expected to move towards the poles in latitude or upward in elevation.

4.2 Climate Change

Climate change, Earth's climate periodic modification brought as a result of atmospheric changes as well as atmosphere and other various geological, biological, geographic factors interaction between them within earth system. The atmosphere

is like the dynamic fluid which is always in the continuous motion. The direction of motion and physical properties and its rate are stimulated by different factors, including the geographic position, solar radiation, ocean current, chemistry of atmosphere, continents geographic position, the location and orientation of mountain ranges, and vegetation growing on the land surface.

Through time, all these factors change. Some factors changes at very short timescales for example surface vegetation, the heat distribution within the oceans, atmospheric chemistry.

Others change over very long timescales, like the location and height of mountain ranges and the position of continents.

Therefore climate varies at every conceivable timescale because climate results from the motion and the physical properties of atmosphere. Climate is sometimes called the average weather of a specific location with such features like humidity, precipitation, windiness and temperature. The more accurate definition would be its mean state and the variability of these variables over some extend of time. Both the statements about climate confirms that the weather is always variable, instable in the atmosphere. As weather changes from day to day so therefore climate also varies, from the cycle of day-night on daily basis up to geologic time hundreds of millions of years long. So the climate variation is a redundant expression.

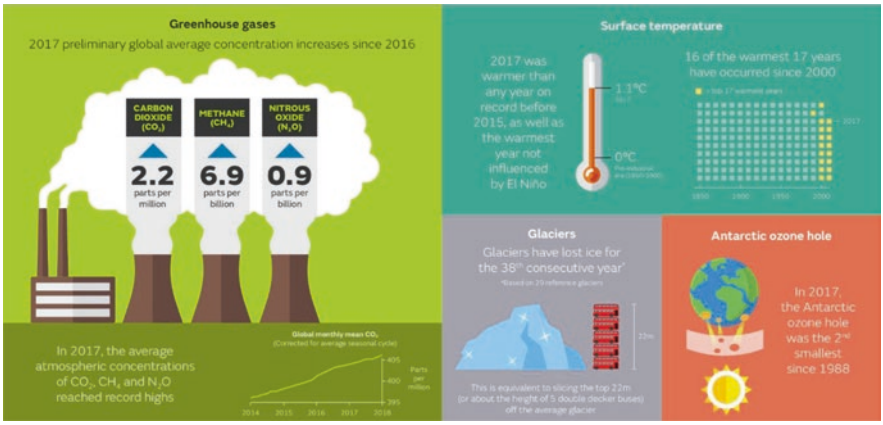
Not even two years are same nor any two millennia. This article is about the variation of climate and the changes occurred within the natural feature's integrated set and the phenomenon is called the Earth system. The evidence about climate change is well elaborated as the principal mechanisms that are the main causing agents throughout the earth history.

At the end, well explained description about the climate change ranging from all geologic time to the life span of humans is given over many different time scales.

> *Climate change is the long term shift in the pattern of earth's weather and temperatures. This planet has had many ice ages and extreme temperature seasons since its birth about 4.6 billion years. So what's wrong now?*

About 11,000 years ago last ice age ended and the climate of earth has been relatively stable along with an average of 14 °C global temperature. But the global temperature have risen during 20th and 21st centuries due to the rise in atmospheric CO_2 (carbon dioxide). Atmospheric carbon dioxide has increased by over 40%, the level that is recorded in at least 800 thousand since the Industrial Revolution. Increase in temperature causes the warming of our climate system and the multiple indicators are alarming that our climate is changing. The snowfall rate is decreased and ice have been diminished, rise in the sea level is observed, greenhouse gases ratio in the atmosphere is exceeded from normal to critical level, temperature of atmosphere and the oceans is increased.

Infographic issued by the Bulletin of the American Meteorological Society, given below shows the major climatic changes.



4.3 Higher Temperatures

About 1 °C Global average surface temperature is increased since the 1850s. In the instrumental record each of the last 3 (three) decades has been successively warmer than any other preceding decade and since the year 2001, 16 of the 17 warmest years on record have occurred during these years.

4.4 Changing Rainfall

In the mid-latitudes of the northern hemisphere, the rainfall has increased since twentieth century beginning. Changes between the seasons of different regions are also observed. For example the average decrease is observed in the UK's summer rainfall while increase in winter rainfall. Evidences also confirms the heavy rainfall become more intensive over the North American region. Rainfall long-term records are needed to resolve any trend from natural changes for some areas.

4.5 Climate Change Threats to Costal Plan Lives

Behavior of the species are mainly affected due to the severe changes in the seasons (such as spring starts before its actual time and autumn starts later), like birds are shifting the migration pattern and the butterflies appear early in the year.

4.5.1 Retreating Glaciers

The shrinkage rate has been increased from last decades due to melting of glaciers all over the globe that exist in the Andes, Himalayas, Alaska, Alps and Rockies.

4.5.2 Sea Ice

Since the late 1970s, decline in the arctic sea-ice has been observed in extent by about 3.9% or 0.6 million sq km per ten year time. Since 1979, the decrease in arctic sea-ice extent by 13.4% in summer per decade. While Antarctic sea-ice is more stable at the same time, since autumn 2016, most of the areas had been at very low levels.

4.5.3 Ice Sheets

The world's major fresh water reservoirs (The Greenland and Antarctic ice sheets) are melting at an accelerating rate.

4.5.4 Coastal Areas

Where water and land join to create an environment with other environmental factors, such areas are known as coastal areas. Hurricanes and El Niño, responsible for the migration of aquatic and other forms of life, the significant amount of damage to ecosystems of coastal areas, reduction in the food supplies and ecosystem disturbance and unbalanced ecosystem. Many acres of coastal region's wetland has been destroyed by Katrina, Hurricanes Andrew and Rita around the Mexican gulf and Florida but still not yet the effects of this destruction are clear that what will happen in future. Coastal areas facing the most significant problems such as runoff from agricultural, industrial and municipal areas. This can result in the higher pollutant level in the waters of coastal areas, it also nourish the algae which can be harmful for both aquatic life and humans. According to the fisheries, coastal areas are particularly important. Coastal fish population and their habitats are at great risk due to the potential contamination of ocean waters and coastal, overfishing and over fishing practices. While pressure on native stocks can be reduced by fish farming (farm-raised fish), these farm-raised fishes can escape and compete with native breed and become a dominant specie. Through cruise ships and marine vessels these invasive species are introduced to the coastal waters.

4.6 Sea Level Rises

Global mean sea level has been rise by more than eight inches since 1900. In recent decades the sea level rise has increased over the last century around 1.7 mm per year to 3.3 mm per year since 1990s.

4.6.1 Sea Level Rise and Climate Change

Since late nineteenth century, the increase in the mean surface temperature of globe is observed which got the attention of academia and governments in very short duration.

IPCC (Intergovernmental Panel on Climate Change) measured the global climate change effect five times from 1990s on human socioeconomic system and natural ecosystems.

According to the 5th IPCC report of the ocean temperature and global combined land data showed 0.89 °C increase over the period of 1901–2012. Over the period of 1901–2010, the mean sea level worldiwde is increased by 0.19 m and between 1901 and 2010. mean sea level rise rate was 1.7 mm per year. Rise in the temperature warms the ocean water and causes the expansion of sea level and also melt the sheets of ice along with the glaciers which contributes the rise of three-quarters.

From last 800,000 years, the atmospheric carbon dioxide, nitrous oxide (dinitrogen monoxide) and methane were 390.5 ppm, 390.5 ppb and 1803.2 parts per billion were higher than experienced and greater than before by 40, 20, 150% since before the industrial era.

Since the mid-twentieth century, the changes observed in the intensity and frequency of extreme events of weather climate are intensifying on world wide scale. Through the observation of frequency of extremely warm and extreme precipitation events, it is clearly showed. Coastal plant life major role is the vegetation in that wetland ecosystem.

In global ecosystem, the role of vegetation is obvious. Particularly, under the pressure of climate change and the activities of human beings, the vegetation of wet coastal land play an important role which is concise as under:

4.6.1.1 Carbon Fixation, Storage of Carbon

For the greenhouse gases, coastal wetland is the vital “source” and “sink”. Most important role of the “sink” is that the wetland vegetation have maximum rate of sequestration of carbon with the minimum rate of methane emission. UNEP (United Nations Environment Program) and FAO (Food and Agriculture Organization) along with the other 4 departments in 2009, released the report about ocean carbon sink. According to United Nations Environment Program (UNEP), most of the

Fig. 4.1 The banks of the Daly Estuary (Australia), is covered by Mangrove roots

world's biomedical carbon is taken by the vegetated habitats of oceans and called the blue carbon like by seagrasses, salt marshes and mangroves.

Coastal wet land vegetation biomass is 0.05% more than terrestrial vegetation. About 862–1650 Tg CO2 (Tg = 1012 g) of carbon is captured and stored per year through the blue carbon ecosystem which is ten-fifty times more than forest.

4.6.1.2 Disaster Mitigation

In the rainy season as buffer zone (between the oceans and land), the vegetation of coastal wet land is capable to store sufficient amount of water and reduces the flood disasters pressure. The Root system of the vegetation have an essential role of formation of land which also absorb the intertidal sediments which mitigate the erosion action on coast line by waves. The notable example is the mangrove forest that is also known as "Chlory the Ocean Guard" which reduces the damage ratio by protecting the crops from extremely saline and strong winds. In Fig. 4.1, the upper bank of Daly Estuary, Australia, is covered by mangrove roots which show resistance against the erosion of upper banks but it's less useful in the case of lower banks undercutting.

1. **Marine habitat**:
   Habitat for fish, waterfowl of winter, shrimp and endangered rare species (manatees or sea cows, turtles etc.) Is provided by the aquatic vegetation communities are found in marine.
2. **Plant purification**:

In the surrounding water, submerged aquatic vegetation's tissues have the concentration of heavy metal of about 100,000 times higher than others. Some species can successfully degrade the sewage like water hyacinth, bulrush etc.

4.7 Vegetation Succession Under Climate Change with the Factors of Driving and Response Analysis

Under acceptable natural condition, the vegetation of the coastline shows the encouraging succession. However, coastal wetland vegetation cannot tolerate the environmental factors effect along with the global climate change otherwise it will leads towards the regressive succession of vegetation and landscape fragmentation of vegetation and some other magnitudes.

4.7.1 Progressive Vegetation Succession Under Natural Environments

To evaluate the succession law of wetlands vegetation, 3 kinds of habitats are chosen as example that are discussed below:

1. Estuary delta: In estuarine delta the distribution of vegetation is zonal because of salinity of soil difference in three-dimensional distribution. From the bare flat, the community of vegetation succession starts such as wing-alkali those vegetation appears first that are highly salt tolerant. The community of medium-low vegetation appears as increase in litter in surface and vegetation such as Reed-Alkali.

   The non-zonal top community (Tamarix Chinesis) formed eventually due to ground water level reduction and increase in topography.
2. Tidal flat wetland: Tidal flat wetland vegetation zonal distribution is horizontal. From the vegetation that are salinity tolerant, succession starts along with coastal beach uplift, soil salinity decreases along with perennial wet plant invasion and process of Desalination of Soil accelerated by vegetation litter. The community of medium vegetation becomes dominant and soil is further biochemical.
3. Mangrove wetlands: Along with the gulf or estuary coastline, the forest of mangrove often form that is a strip distribution. From the non-mangroves plants the pioneer communities often formed having the ability to stand against the strong waves of wind and leanness. Typical mangrove communities with the demineralization development, developed the dominant position in their respective ecosystem. Reduction after soil salinity, the formation of pioneer community starts while Succession of vegetation is always dependent on the salinity resistance, resistance against the waterlogging and barren species, no matter what type of the coastal wetlands are. Gradually then environment achieve stability which play an important role in the growth of vegetation. At last, the stable and whole comprehensive ecosystem for the vegetation is formed. Development of the community of wetland vegetation beside table of water range is elaborated in Fig. 4.2.

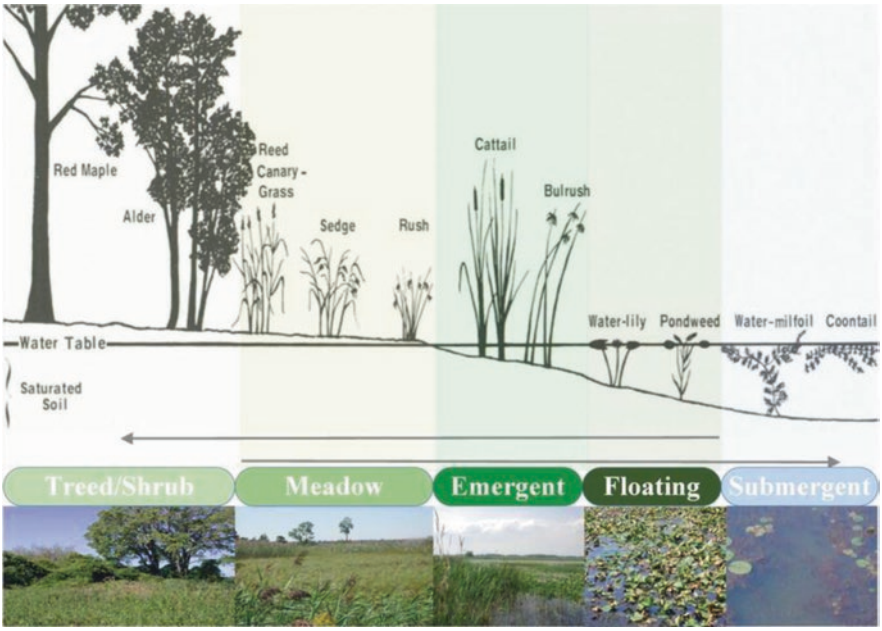


Fig. 4.2 Development of vegetation community with continuum of water table (Mortsch et al. 2006)

4.7.2 Vegetation's Successions Driving Factors Under Climate Change

Succession of vegetation characteristics along with the effect of elevation and geographic position, it also depends on the factors like soil nutrient, water content as well as with the activities of human beings. Under climate change, some factors become dominant and magnified.

4.7.2.1 Changes in the Elevation Relative to Habitat

Sea level rise can be influenced by increase in coastal wetland elevation in the result of accumulation of tidal flat sediments. First of all, if the rate of sediments accumulation is nearly same to the rise in sea level, the coastal wetland relative elevation will be constant and the effect on vegetation growth will be minimum by the sea level rise, as shown in Fig. 4.3a. Furthermore, as in Fig. 4.3b, in case of increase in the sediment accumulation rate than the sea level rise, this will be in favor of vegetation habitat area because the growth area will enlarge. Thirdly, as in Fig. 4.3c, the growth and survival of the vegetation will be affected in case the rate of sea level rise is greater than sediment accumulation rate because it will result the decrease in relative elevation and will promote the flooding frequency as these situations can

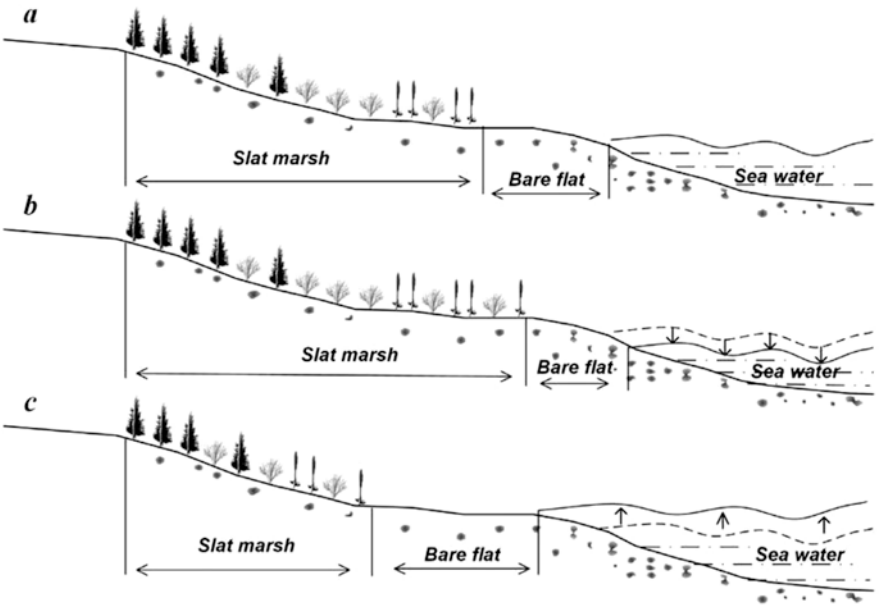


Fig. 4.3 Coastal wetland vegetation's sketch in response of rise in sea level. (*a*) Unchanged sea level; (*b*) Sea level dropped; (*c*) Sea level raised

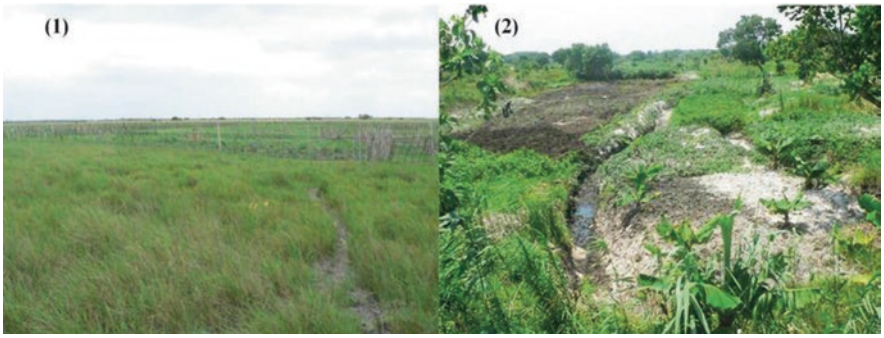


Fig. 4.4 (*1*) Economic plantations on coastal plain of Maputaland from the last 20 years; (*2*) drained and destructed wetland

diminish the life of plants By the Suggestion of some other researches, in the upper layers of soil, the processes of accumulation is slower than physical-biological time-effect. In the coastal wetland new shallow strata just like estuary delta, layer of soil is compressed that is under the artificial coastal engineering action's, which is easy for soil subsidence.

4.7.2.2 Coastal Habitat's Net Loss

Under the influence of sea level rise, the coastal wetland can be preserved by occupying formerly upland and inland sites extension. However, coastal wetland ability to move landward depends on the topography relationship. As the sites of lower elevation become submerged, the boundary of landward marsh slope may expand. The effective barrier of slop will inhibit the growth of plant communities in such geographic location and as a result, the area for coastal vegetation is squeeze. In few typical coastal wetland, the movement of marsh edge is modeled by the scientists of USGS and the University of Duke that this is not just the rise in sea level but also activities of human beings that stimulates inland marsh movement. Rate of sediment accumulation is very low as compared to human reclamation rate, may be speeded up in the initial stages of inland evolution and reclamation of coastal wetland. In Africa, the survived agricultural plantation took place on the Maputaland coastal plain's wettest zones of wetland, as shown in the Fig. 4.4(1). However, coastal wetland natural evolution purpose is different from human reclamation, so for vegetation habitats inland evolution this will become the main barrier, for example, wetland is destructed and drained due to reclamation of human beings, as shown in the second Figure.

4.7.2.3 Salinity, CO_2 and Other Factors

Salinity increases as the level of sea arise because the water move farther inland and expose the communities of vegetation to the stress of salinity. The vegetation direction is mainly controlled by relative elevation and habitat area change by the soil salinity succession. The area near the tidal erosion or low-lying area near to the sea have good ratio of salt-tolerant plants. The decrease in soil salinity occurs as we move from low to high-tidal flat and diversity in the salinity tolerance of plants confirms that, because the plants on high-tidal flat will be less salinity tolerant. As elevation decrease from high to low, the depth of ground water increases in the result of water's capillary action to reach surface and affect the level of salinity. Due to the observed climatic changes, CO_2 concentration increases in the atmosphere. The concentration of dissolved inorganic carbon in water also

increases as a result of increase of carbon dioxide concentration in atmosphere. Communities of vegetation can be affected by the tropical storms which are increased in climate change result. From little increase in salinity, the flooding was very important in the survival and growth of most species but severe increase in the salinity is very harmful to all kind of vegetation communities tested flooding extent regardless.

4.7.3 Vegetation Analysis in Various Factors Response

If rise in sea level continuously stable then in coming next few decades the land area will be converted into open water from freshwater marsh and coastal salt on the large scale and change in the habitat, structure and movement of vegetation will occur. In various factors response, experiments performed in various fields and labs on vegetation evaluated the great succession.

Various greenhouse experiments shows that the plant cannot grow well in the highly saline soil but can tolerate the salinity little bit because of physiological tolerance as plants are known for their competition for nutrients and water. In moderate to high saline environment, high salinity tolerant vegetation occupy leading occurrence but will be weak competitor at low salinity as compared to that of low tolerant community. In response to climate change, monitoring for long term can help in the structure and dynamics of forest which suggest that the structure of forest dynamic quantification and climate change response through long term monitoring suggest that:

1. The seedling population in the forests of bottom land significantly alter through the climate change with increase in drought and sapling layer recruitment, and influence ultimately over the structure canopy of story.
2. shade-intolerant and early successional species may form due to the disturbance bounded with the storms and floods and
3. Due to the damage of hurricanes and strong storms, the mangrove forest structural composition will disturb and the mangrove forest will become shrink in size.

In the laboratory, the higher concentration were measured of dissolved carbon dioxide in the photosynthetic activity of some vegetation of submerged freshwater species like Hydrilla, coontail and wild celery and some seagrasses like shoal grass. Increase in the photosynthetic activities is observed in all four species in the higher concentration of carbon dioxide response but the growth of plant tissues is not observed by the increased carbon dioxide ratio. C-N increased ratio in the tissues of

plants results in the low quality forage for winter waterfowl as they used it as nutrient source.

4.8 Changes in Structure of Vegetation Community

Climate change cause change in the community's structure internally like erosion of coast line, stress of salinity and storm surge. The increased number of landscape patches of vegetation showed discrete distribution E.g., from the fresh-water insufficiency, in vegetation transformation process to saline-marsh from wet unripe vegetation, in landscape and disorder two types of vegetation disrupted was molted. Between different types of communities, structure trend of community isn't fragmented but distribution is tend to be concentrated which form large plaque For example, where the artificial crop and natural coastal vegetation are connected, the artificial killing wetland vegetation and other crops eroded except cash crops. In natural existing population of wetland vegetation the variation exist on the basis of salt-tolerance, so the new varieties can be developed that have tolerance against the salinity and the efforts for those communities that are killed by the saltwater intrusion can be done by the reforestation. Thus, the artificial cultivated plants with the tolerance of salinity, drought and other stress tolerant characters can be expanded rapidly. Additionally, the opportunities for the other exotic species can be developed by enhancing the invasion rate into natural stands.

4.9 Changes of Vegetation Succession Direction

Coastal wetland's natural development process is disrupted due to the climate change which is causing the unreasonable or reverse succession of vegetation communities of wetland which speed up the degradation of the coastal wetland, as shown in the Fig. 4.5. Due to the lack of freshwater, the vegetation of wetland wet-unripe is degraded into saline-marsh vegetation, the decrease in the elevation of surface is the result of low accumulation rate than sea level rise. By the shoreline erosion, the inter tidal community of sparse vegetation is retreated, opposite succession in the wetland's beach bare-light. By the rise in sea level, the blockage of land movement of the vegetation of wetland is caused by the economic crops that are planted by artificial reclamation. In the result of Irrational tillage, the ammonia nitrogen content and organic matter decreased, through which the vegetation community's suuccession will occur or it will facilitate the harmfull species invasion.

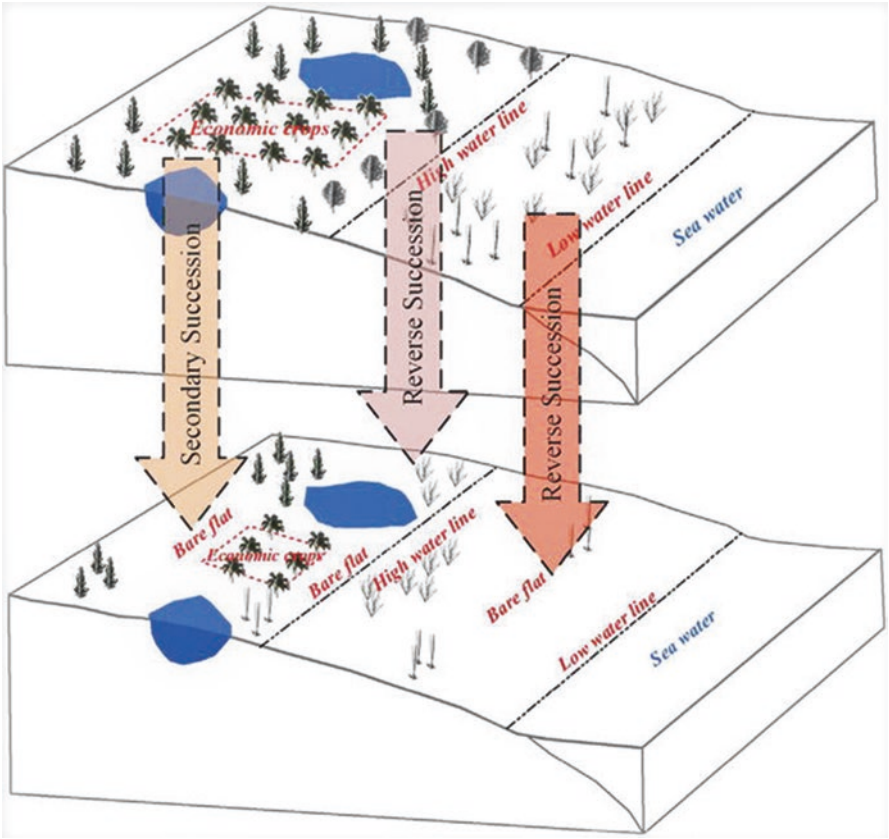


Fig. 4.5 The sketch map of direction of vegetation succession change

References

Adnan M, Zahir S, Fahad S, Arif M, Mukhtar A, Imtiaz AK, Ishaq AM, Abdul B, Hidayat U, Muhammad A, Inayat-Ur R, Saud S, Muhammad ZI, Yousaf J, Amanullah Hafiz MH, Wajid N (2018) Phosphate-solubilizing bacteria nullify the antagonistic effect of soil calcification on bioavailability of phosphorus in alkaline soils. Sci Rep 8:4339. https://doi.org/10.1038/s41598-018-22653-7

Akram R, Turan V, Hammad HM, Ahmad S, Hussain S, Hasnain A, Maqbool MM, Rehmani MIA, Rasool A, Masood N, Mahmood F, Mubeen M, Sultana SR, Fahad S, Amanet K, Saleem M, Abbas Y, Akhtar HM, Waseem F, Murtaza R, Amin A, Zahoor SA, ul Din MS, Nasim W (2018a) Fate of organic and inorganic pollutants in paddy soils. In: Hashmi MZ, Varma A (eds) Environmental pollution of paddy soils, soil biology. Springer, Cham, pp 197–214

Akram R, Turan V, Wahid A, Ijaz M, Shahid MA, Kaleem S, Hafeez A, Maqbool MM, Chaudhary HJ, MFH M, Mubeen M, Sadiq N, Murtaza R, Kazmi DH, Ali S, Khan N, Sultana SR, Fahad S, Amin A, Nasim W (2018b) Paddy land pollutants and their role in climate change. In: Hashmi MZ, Varma A (eds) Environmental pollution of paddy soils, soil biology. Springer, Cham, pp 113–124

Aziz K, Daniel KYT, Fazal M, Muhammad ZA, Farooq S, Fan W, Fahad S, Ruiyang Z (2017) Nitrogen nutrition in cotton and control strategies for greenhouse gas emissions: a review. Environ Sci Pollut Res 24:23471–23487. https://doi.org/10.1007/s11356-017-0131-y

Fahad S, Bano A (2012) Effect of salicylic acid on physiological and biochemical characterization of maize grown in saline area. Pak J Bot 44:1433–1438

Fahad S, Chen Y, Saud S, Wang K, Xiong D, Chen C, Wu C, Shah F, Nie L, Huang J (2013) Ultraviolet radiation effect on photosynthetic pigments, biochemical attributes, antioxidant enzyme activity and hormonal contents of wheat. J Food Agric Environ 11(3&4):1635–1641

Fahad S, Hussain S, Matloob A, Khan FA, Khaliq A, Saud S, Hassan S, Shan D, Khan F, Ullah N, Faiq M, Khan MR, Tareen AK, Khan A, Ullah A, Ullah N, Huang J (2014a) Phytohormones and plant responses to salinity stress: a review. Plant Growth Regul 75(2):391–404. https://doi.org/10.1007/s10725-014-0013-y

Fahad S, Hussain S, Bano A, Saud S, Hassan S, Shan D, Khan FA, Khan F, Chen Y, Wu C, Tabassum MA, Chun MX, Afzal M, Jan A, Jan MT, Huang J (2014b) Potential role of phytohormones and plant growth-promoting rhizobacteria in abiotic stresses: consequences for changing environment. Environ Sci Pollut Res 22(7):4907–4921. https://doi.org/10.1007/s11356-014-3754-2

Fahad S, Hussain S, Saud S, Tanveer M, Bajwa AA, Hassan S, Shah AN, Ullah A, Wu C, Khan FA, Shah F, Ullah S, Chen Y, Huang J (2015a) A biochar application protects rice pollen from high-temperature stress. Plant Physiol Biochem 96:281–287

Fahad S, Nie L, Chen Y, Wu C, Xiong D, Saud S, Hongyan L, Cui K, Huang J (2015b) Crop plant hormones and environmental stress. Sustain Agric Rev 15:371–400

Fahad S, Hussain S, Saud S, Hassan S, Chauhan BS, Khan F et al (2016a) Responses of rapid viscoanalyzer profile and other rice grain qualities to exogenously applied plant growth regulators under high day and high night temperatures. PLoS One 11(7):e0159590. https://doi.org/10.1371/journal.pone.0159590

Fahad S, Hussain S, Saud S, Khan F, Amanullah HS Jr, Nasim W, Arif M, Wang F, Huang J (2016b) Exogenously applied plant growth regulators affect heat-stressed rice pollens. J Agron Crop Sci 202:139–150

Fahad S, Hussain S, Saud S, Hassan S, Ihsan Z, Shah AN, Wu C, Yousaf M, Nasim W, Alharby H, Alghabari F, Huang J (2016c) Exogenously applied plant growth regulators enhance the morphophysiological growth and yield of rice under high temperature. Front Plant Sci 7:1250. https://doi.org/10.3389/fpls.2016.01250

Fahad S, Hussain S, Saud S, Hassan S, Tanveer M, Ihsan MZ, Shah AN, Ullah A, Nasrullah KF, Ullah S, Alharby HNW, Wu C, Huang J (2016d) A combined application of biochar and phosphorus alleviates heat-induced adversities on physiological, agronomical and quality attributes of rice. Plant Physiol Biochem 103:191–198

Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, Sadia S, Nasim W, Adkins S, Saud S, Ihsan MZ, Alharby H, Wu C, Wang D, Huang J (2017) Crop production under drought and heat stress: plant responses and management options. Front Plant Sci 8:1147. https://doi.org/10.3389/fpls.2017.01147

Fahad S, Muhammad ZI, Abdul K, Ihsanullah D, Saud S, Saleh A, Wajid N, Muhammad A, Imtiaz AK, Chao W, Depeng W, Jianliang H (2018) Consequences of high temperature under changing climate optima for rice pollen characteristics-concepts and perspectives. Arch Agron Soil Sci. https://doi.org/10.1080/03650340.2018.1443213

Fahad S, Rehman A, Shahzad B, Tanveer M, Saud S, Kamran M, Ihtisham M, Khan SU, Turan V, Rahman MHU (2019a) Rice responses and tolerance to metal/metalloid toxicity. In: Hasanuzzaman M, Fujita M, Nahar K, Biswas JK (eds) Advances in rice research for abiotic stress tolerance. Woodhead Publ Ltd, Cambridge, pp 299–312

Fahad S, Adnan M, Hassan S, Saud S, Hussain S, Wu C, Wang D, Hakeem KR, Alharby HF, Turan V, Khan MA, Huang J (2019b) Rice responses and tolerance to high temperature. In: Hasanuzzaman M, Fujita M, Nahar K, Biswas JK (eds) Advances in rice research for abiotic stress tolerance. Woodhead Publ Ltd, Cambridge, pp 201–224

Habib ur R, Ashfaq A, Aftab W, Manzoor H, Fahd R, Wajid I, Md Aminul I, Vakhtang S, Muhammad A, Asmat U, Abdul W, Syeda RS, Shah S, Shahbaz K, Fahad S, Manzoor H, Saddam H, Wajid N (2017) Application of CSM-CROPGRO-cotton model for cultivars and optimum planting

dates: evaluation in changing semi-arid climate. Field Crops Res. https://doi.org/10.1016/j.fcr.2017.07.007

Hafiz MH, Wajid F, Farhat A, Fahad S, Shafqat S, Wajid N, Hafiz FB (2016) Maize plant nitrogen uptake dynamics at limited irrigation water and nitrogen. Environ Sci Pollut Res 24(3):2549–2557. https://doi.org/10.1007/s11356-016-8031-0

Hafiz MH, Muhammad A, Farhat A, Hafiz FB, Saeed AQ, Muhammad M, Fahad S, Muhammad A (2019) Environmental factors affecting the frequency of road traffic accidents: a case study of sub-urban area of Pakistan. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-04752-8

Kamran M, Wenwen C, Irshad A, Xiangping M, Xudong Z, Wennan S, Junzhi C, Shakeel A, Fahad S, Qingfang H, Tiening L (2017) Effect of paclobutrazol, a potential growth regulator on stalk mechanical strength, lignin accumulation and its relation with lodging resistance of maize. Plant Growth Regul 84:317–332. s10725-017-0342-8

Mortsch L, Snell E, Ingram J (2006) Chapter 2. Climate variability and changes within the context of the Great Lakes basin. In: Mortsch L, Ingram J, Hebb A, Doka S (eds) Great Lakes coastal wetland communities: vulnerability to climate change and response to adaptation strategies. Environment Canada and the Department of Fisheries and Oceans, Toronto, pp 9–19

Muhammad Z, Abdul MK, Abdul MS, Kenneth BM, Muhammad S, Shahen S, Ibadullah J, Fahad S (2019) Performance of Aeluropus lagopoides (mangrove grass) ecotypes, a potential turfgrass, under high saline conditions. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-04838-3

Qamar-uz Z, Zubair A, Muhammad Y, Muhammad ZI, Abdul K, Fahad S, Safder B, Ramzani PMA, Muhammad N (2017) Zinc biofortification in rice: leveraging agriculture to moderate hidden hunger in developing countries. Arch Agron Soil Sci 64:147–161. https://doi.org/10.1080/03650340.2017.1338343

Sajjad H, Muhammad M, Ashfaq A, Waseem A, Hafiz MH, Mazhar A, Nasir M, Asad A, Hafiz UF, Syeda RS, Fahad S, Depeng W, Wajid N (2019) Using GIS tools to detect the land use/land cover changes during forty years in Lodhran district of Pakistan. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-06072-3

Saud S, Chen Y, Long B, Fahad S, Sadiq A (2013) The different impact on the growth of cool season turf grass under the various conditions on salinity and draught stress. Int J Agric Sci Res 3:77–84

Saud S, Li X, Chen Y, Zhang L, Fahad S, Hussain S, Sadiq A, Chen Y (2014) Silicon application increases drought tolerance of Kentucky bluegrass by improving plant water relations and morph physiological functions. Sci World J 2014:1–10. https://doi.org/10.1155/2014/368694

Saud S, Chen Y, Fahad S, Hussain S, Na L, Xin L, Alhussien SA (2016) Silicate application increases the photosynthesis and its associated metabolic activities in Kentucky bluegrass under drought stress and post-drought recovery. Environ Sci Pollut Res 23(17):17647–17655. https://doi.org/10.1007/s11356-016-6957-x

Saud S, Fahad S, Yajun C, Ihsan MZ, Hammad HM, Nasim W, Amanullah Jr, Arif M, Alharby H (2017) Effects of nitrogen supply on water stress and recovery mechanisms in Kentucky bluegrass plants. Front Plant Sci 8:983. https://doi.org/10.3389/fpls.2017.00983

Shah F, Lixiao N, Kehui C, Tariq S, Wei W, Chang C, Liyang Z, Farhan A, Fahad S, Huang J (2013) Rice grain yield and component responses to near 2°C of warming. Field Crop Res 157:98–110

Wajid N, Ashfaq A, Asad A, Muhammad T, Muhammad A, Muhammad S, Khawar J, Ghulam MS, Syeda RS, Hafiz MH, Muhammad IAR, Muhammad ZH, Muhammad Habib ur R, Veysel T, Fahad S, Suad S, Aziz K, Shahzad A (2017) Radiation efficiency and nitrogen fertilizer impacts on sunflower crop in contrasting environments of Punjab, Pakistan. Environ Sci Pollut Res 25:1822–1836. https://doi.org/10.1007/s11356-017-0592-z

Yang Z, Zhang Z, Zhang T, Fahad S, Cui K, Nie L, Peng S, Huang J (2017) The effect of season-long temperature increases on rice cultivars grown in the central and southern regions of China. Front Plant Sci 8:1908. https://doi.org/10.3389/fpls.2017.01908

Zahida Z, Hafiz FB, Zulfiqar AS, Ghulam MS, Fahad S, Muhammad RA, Hafiz MH, Wajid N, Muhammad S (2017) Effect of water management and silicon on germination, growth, phosphorus and arsenic uptake in rice. Ecotoxicol Environ Saf 144:11–18