Biological Diversity:

Current Status and Conservation Policies

Volume 1

Editors
Vinod Kumar | Sunil Kumar | Nitin Kamboj | Temin Payum

Co-editors
Pankaj Kumar | Sonika Kumari

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Preface

Dear Readers !

In recent times, planet earth has gone through substantial climate changes which have resulted in adverse effects on its living biota. Rapid changes in the environmental composition have made it unsuitable for the survival of certain organisms making them completely extinct or near extinction. In fact, the activities which are affecting the environment and its components are both natural and anthropogenic. Still, there is a significant contribution of humans in damaging the biological diversity of the earth. Many of the organisms have already been extinct due to extensive poaching and killing for the personal benefit of humans. Therefore, the time has come to conserve all these threatened species which are an integral part of our earth system and somehow contribute to ecosystem balancing and functioning.

The present book entitled "Biological Diversity: Current Status and Conservation Policies" has been designed to bind prime knowledge of climate change-induced impacts on various aspects of our environment and its biological diversity. The book also contains updated information, methods, and tools for the monitoring and conservation of impacted biological diversity. The book compilation included 23 selective chapters from nearly 59 authors. Each chapter contains detailed information on the proposed titles along with possible explanations using relevant tables and illustrations. The book chapters also present novel and eco-friendly approaches to the conservation of different spheres of our environment.

Lastly, the editors are thankful to the contributors who submitted their precious findings and views related to the book theme and to make it succeeded. We hope that this book will help the readers in its best to provide them the relevant information.

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Chapter
[1]

Biological diversity: Introduction, values, threats and conservation measures

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Abstract

Earth is the only know planet to have life till date. However, life on the earth has evolved from microscopic organisms (microbes) that left signals of their presence in rocks about 3.7 billion years old to the present time's complex plant and animal forms. Earth has created different forms of life in four different patterns of evolution *viz*., convergent evolution, divergent evolution, parallel evolution, and coevolution. From these evolutions, different types of animals and plants have emerged as a result of continuous but very slow changes in the genetic materials (RNA and DNA). At present, earth's species range from 10 million to 14 million out of which plants (17%), protists (4%) prokaryotes (0.3%), fungi (4.7%), insects (54%), and other animals (20%) are major candidates. All these species play an important role in earth and it's environmental sustainability with various values. In this, recently emerged anthropogenic activities has contributed in rapid vanishing of biodiversity affecting mostly all compartments of life. However, various steps are being taken at national and international level such as creation of national parks, wildlife sanctuaries, conservation reserves, community reserves, biosphere reserves, gene banks, etc. This chapter describes the status and importance of biodiversity conservation in present scenario.

Keywords Biological diversity, Conservation, IUCN, Climate Change, Endemic species

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Introduction

Biodiversity originates from Greek word *Bios* means life and Latin word *Diversitas* means form or variety. It refers to different forms of life (plants, animals, fungi and microbes) on planet Earth. The term 'biological diversity' was coined by Thomas Lovejoy in 1980 and the term 'biodiversity' was coined by Walter G. Rosen in 1986 at National Forum on Biodiversity held in Washington (Sarkar, 2019). Biodiversity or biological diversity can range from smallest known life forms *Nanobes* with diameter 20-150 nm, smallest known bacteria (Unwins, 1999) to blue whale having length up to 110 feet and from extreme cold to extreme hot. Different form of life exists at any extreme conditions with which one can depict the range of diversity on the Earth. Biological diversity has no particular/ standardised definitions. Different definitions were given from time to time to explain biodiversity. Biodiversity or biological diversity defined as the variation among different genetic, species and ecosystem levels in the biological system (Bartkowski *et al*., 2015).

"*Biological diversity is defined as the variability among all the sources including, inter alia, land (terrestrial), marine and aquatic ecosystems and the ecological complexes of which they are part it includes diversity within species, between species and of the ecosystems":* Convention on Biological Diversity, 1992 (signed by United Nation Earth Summit held in Rio de Janeiro).

According to Noss (1990), "Biodiversity is not only the variability among genetic, species and ecosystem level in a defined area but it should also include the various interspecific interactions, biogeochemical cycles and natural disturbances. It should include the range of diversity indices and quantitative factors along with quantitative factors should be considered as an indicator for biological disruption". Biodiversity is defined as the abundance, number, composition, interactions, spatial distribution, population, species, communities and their functions, genotypic and phenotypic traits, landscape units in a biological system (Díaz *et al.,* 2009). It is the interaction between different types of diversities like genetic, species and ecosystem diversity.

Types of biodiversity

Generally, the biological diversity has three types, these includes genetic diversity, species diversity and ecosystem diversity (Figure 1). The detailed description of genetic diversity, species diversity and ecosystem diversity are as follows:

Genetic diversity: It refers to the variation in the genetic constitution within a species or within a population. Every organism in this world is different from another in their genetic material. For example, in humans even twins are not exactly similar in their genetic makeup and shows lots of diversity from one another. Likewise, genetic diversity of rice, barley, maize etc. shows variation in the same species. The same species shows difference in their genetic makeup, color, size aroma, shape and

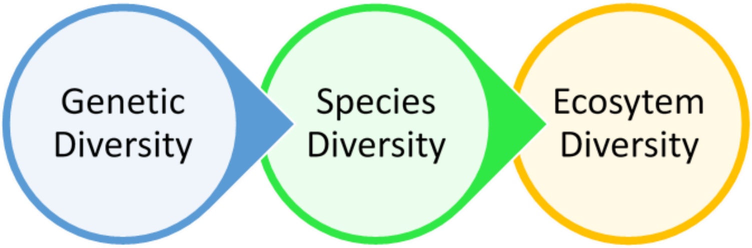

Figure 1. Types of biological diversity.

nutrient content. Due to the genetic diversity species are able to show adaptation and respond to the environmental changes. It is also helpful in evolution and speciation (Carvalho *et al*., 2019).

Species diversity: It is the biological diversity at the most basic level. Species exists in large groups with different physical and biological characters. These species function individually or in a group in the food web. Species interact with each other through different interactions (competition, mutualism etc.) which collectively play an important role in ecosystem dynamics. Species diversity is measured by species richness and relative abundance (White *et al*., 2018).

Ecosystem diversity: An ecosystem consists of both living and non- living components and their interactions with each other. Ecosystem diversity is defined as the diversity among different ecosystems in a region. For example, ecosystems like mountains, desert, grasslands, mangroves show diversity. This type of ecological diversity is more stable and productive as they are capable to tolerate unfavourable environmental conditions (Brierley *et al*., 2016; Kumar *et al*., 2019).

Biodiversity of India and the world

India consists of 10 major biogeographic zones and 27 biogeographical provinces based on their distinctive biota. One biotic province or biogeographical province is different from another in their flora and faunal composition (Table 1). There are over 8.74 million species of eukaryotes on world's land and about 2.21 million species of eukaryotes in ocean water while approximately 10,000 species of prokaryotes on land and out of which 1300 are marine prokaryotes predicted on Earth. There are about 7.7 million species of animals and over 300,000 species of plants (Mora *et al.,* 2011). In this world there are about 1,399,189 species which belongs to kingdom Animalia and in India over 92,873 species belong to this kingdom which constitute 6.64% (ZSI, 2014). There are about 317,950 plants species present in this world. In India there are over 29,015 plant species with 9.13 percent (BSI, 2013). Total number of Insecta, Mammalia, Aves, Reptilia, Pisces, Animalia, Protista in India and the world is given in Figures 2 and 3. There are about 7200 species of Algae, 2500 species of Bryophytes, 1269 species of Pteridophytes, 75 species of Gymnosperms and over 18,000 species of Angiosperms. About 9.13 percent floral diversity is found in India and Angiosperms contributes to over 27% (Figure 4).

Table 1. Distribution of biogeographic zones in India (Source: MoEF, 2009; Singh and Chaturvedi, 2017).

Biogeographic zone	Biogeographic province
Trans-Himalayas	Ladakh mountains
	Tibetan Plateau
	Trans-Himalayan: Sikkim
Himalaya	North-Western Himalaya
	Western Himalaya
	Central Himalaya
	Eastern Himalaya
Indian desert	Kutch
	Thar Desert
Semi-arid	Punjab plains (semi-arid)
	Gujrat, Rajputana
Western ghats	Malabar Plains
	Mountains of Western Ghats
Deccan peninsula	Central Highlands
	Chotta Nagpur
	Eastern Highlands
	Central Plateau
	Deccan South
The Gangetic Plains	Lower Gangetic plains
	Upper Gangetic Plains
The Coasts	West Coast
	East Coast
	Lakshdweep
North-east India	Assam plains
	Shillong Plateau
Islands	Andamans
	Nicobars

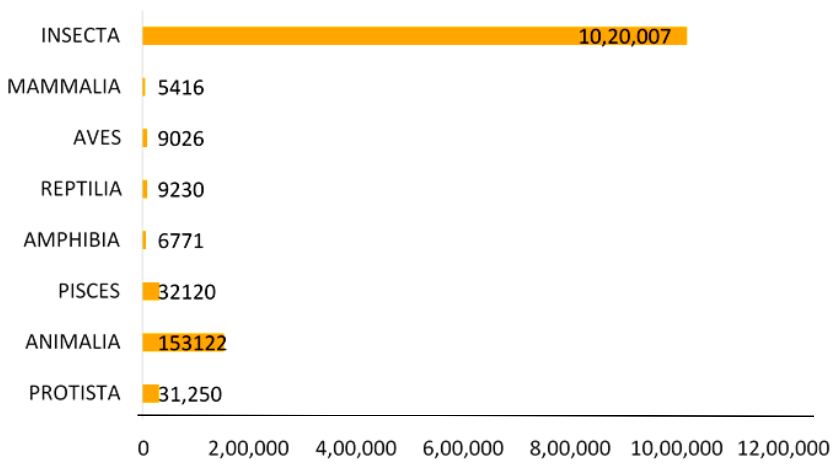

Figure 2. Taxonomic group species of the world (Zoological Survey of India, ZSI, 2014).

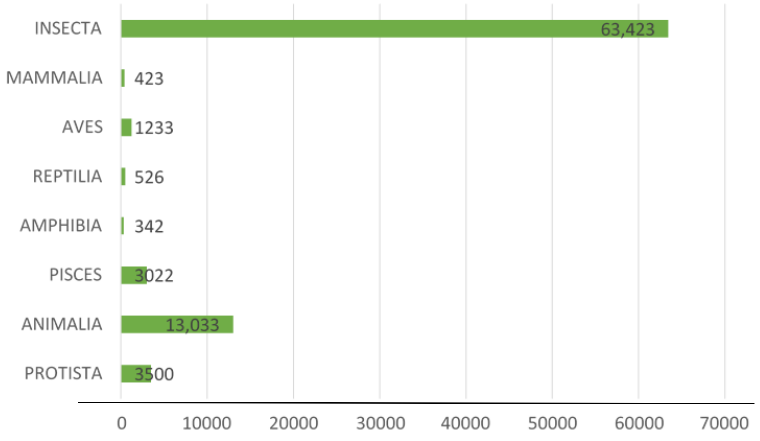

Figure 3. Taxonomic group species of India (Zoological Survey of India, ZSI, 2014).

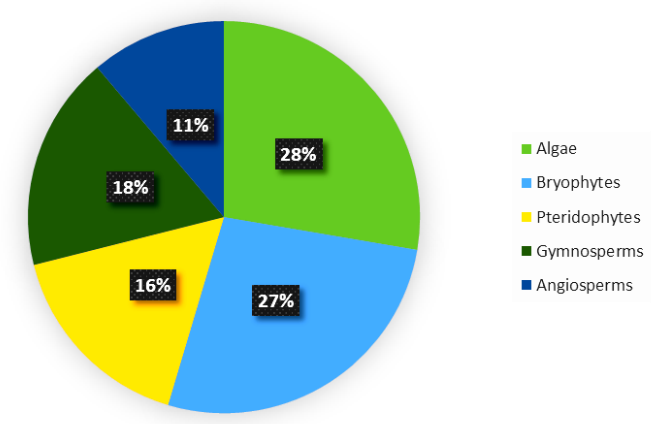

Figure 4. Percentage of floral diversity in India (Source: Botanical Survey of India, BSI, 2013).

Biodiversity hotspots

Biodiversity hotspots are the areas that are extremely rich in flora and fauna and have a high level of endemism, which includes flora and fauna which are under the threat of getting endangered. There are mainly two criteria to be checked to qualify a region under the category of a biodiversity hotspot. (a) It must have at least 1500 or 0.5 % species of vascular plants that are endemic to the region. (b) It has to have lost ≥ 70% of its original native habitat and must be in the threatened list of IUCN (Johnson *et al*., 2015). Based on these criteria around 36 areas of the world qualify as biodiversity hotspots. These covers just 2.5% of Earth's land surface but it constitutes more than half of the world's plant species as endemics i.e., belonging to the particular place only and nearly 43% of mammal, bird, reptile and amphibian species as endemics. Presently there are 36 biodiversity hotspots (Table 2). These areas are of extreme importance and need utmost protection (Huang *et al*., 2018). The 36 biodiversity hotspots of the world have been classified on the basis of location which are North and Central America, Europe and Central Asia, Africa, Asia and Australia and South America.

Table 2. Distribution of biodiversity hotspots in the world (Source: Conservation International/ Biodiversity Hotspots (https://www.conservation.org/).

Biodiversity hotspots	**Location**
Atlantic Forest	Argentina, Paraguay and parts of Brazil
California Floristic Province	California, USA
Cape Floristic Region	Southern tip of South Africa
Caribbean Islands	East of Central America
Caucasus	Near border between Europe and Asia, separating the Black and Caspian seas
Cerrodo	Central Brazil
Chilean Winter Rainfall – Valdivian Forests	Central North of Chile, to the Western regions of Argentina
Coastal Forests of Eastern Africa	Eastern cost of Africa
East Melanesian Islands	North East of Australia
Eastern Afromontane	East African Rift from the Red Sea to Zimbabwe
Forest of East Australia	Eastern Coast of Australia
Guinean Forests of West Africa	Coastal Western Africa
Eastern Himalaya	Parts of India, China, Bhutan, Tibet and Myanmar
Horn of Africa	Northeastern Africa
Indo-Burma	Parts of Bangladesh, India, Myanmar, China, Cambodia, Vietnam, Thailand and Malaysia, Hainan Island and Andaman Island
Irano-Anatolian	Parts of Armenia, Azerbaijan, Georgia, Iraq, Iran, Turkey and Turkmenistan
Indian Ocean Islands	Surrounding Madagascar, Comoros, Mauritius and Seychelles
Japan	Northern Pacific Ocean
Madagascar	Southeast Coast of South Africa
Madrean Pine-Oak Woodlands	Southern part of USA
Maputalanad-Pondoland-Albany	South Eastern Coast of South Africa
Mediterranean Basin	Surrounding the Mediterranean Sea
Mesoamerica	Belize, Guatemala, Central Mexico, Nicaragua and Northern Costa Rica
Mountains of Central Asia	It extends through Afghanistan, China, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan in Central Asia
Mountains of Southwest China	Includes Tibet, Sichuan, Qinghai, Gansu and Myanmar
New Caledonia	South Pacific Ocean
New Zealand	Southwest Pacific Ocean
Philippines	Southeast Asia
Polynesia-Micronesia	Southern Pacific Ocean

Table 2. Continued...

Biodiversity hotspots	Location
Southwest Australia	Southwest part of Australia
Succulent Karoo	Coastal Region of South Africa
Sundaland	Southeastern Asia comprising the Malay Peninsula, Bomeo Island, Java Island and Sumatra Island along with their smaller surrounding Islands.
Tropical Andes	South America: Parts of Andes Mountains
Tumbes-Choco-Magdalena	The Galapagos Island and Pacific Coast of South America
Wallacea	Eastern Indonesia
Western Ghats of India and Islands of Sri Lanka	Indian Peninsula and South of India

Biodiversity hotspots in India

India is rich in biological diversity. The four hotspots present in the Indian subcontinent are Western Ghats of India and Sri Lanka, The Himalayas, Indo- Burma and Sundaland (Sivaperuman *et al*., 2018).

Western Ghats of India and Sri Lanka: These are older than Himalayas, formed by the erosion of Deccan plateau. Geological evidences indicate that they are formed during erosion of Gondwana subcontinent. Western Ghats are covered under six states of India these are Maharashtra, Gujrat, Goa, Karnataka, Kerala and Tamil Nadu. They are the continuous range of mountains along the western edge of peninsular India which covers the area of 160,000 km^2 in a stretch (Yakovlev and Zolotuhin, 2021). The Western Ghats are considered as UNESCO World Heritage Site and one of the "hottest biodiversity hotspots" of the world. These are highly rich in biodiversity and shows high endemism. The western Ghats covers less than 6% area of India but constitutes over 30% of all the floral and faunal diversity found in India (Myers *et al.*, 2000; Bawa *et al.*, 2007). These are present near ocean so good amount of rainfall is received in this region. Different varieties of forests are present in this region which are Evergreen forests, Semi Evergreen forests, Moist Deciduous Forest and Dry Deciduous Forest. The other type of vegetation includes, Savana, High rainfall Savana, Scrub jungles, Peat bogs, Sholas and *Myristica* Swamps. Over 5,916 plant species out of which 3,049 are endemic to Western Ghats of India and Sri Lanka. In addition to plants, 140 species of mammals (18 are endemic with 12.9 % endemism), 191 species of fishes with 72.8% endemism, 178 amphibian species with 73% endemism, 458 species of birds with 7.6 % of endemism and 267 reptile species having 65.2 % endemism found in this biodiversity hotspot (Figure 5) The Nilgiri Hills are located in the Western Ghats and over the population of 10,000 elephants found in this region. The southwestern part of Ghats is also very important for the conservation point of view of tigers as 10% of world's tigers found here (Myers *et al.,* 2000). ***The Himalayas:*** The Himalayas are the youngest and one of the highest mountain ranges. These are formed by the collision between two continental plates, Indian plate and Eurasian plate about 40- 50 million years ago and this collision between the plates is active today (Rana *et al*., 2021).

Table 3. Biological diversity and endemism in the Himalayas biodiversity hotspot (Source: www.cepf.net).

Species group	Total number of Species	Endemic species	Endemism (%)
Plants	10,000	3,160	31.6
Mammals	300	12	4
Birds	980	15	1.5
Reptiles	175	50	28.5
Amphibians	105	40	38
Freshwater Fishes	269	33	12.2

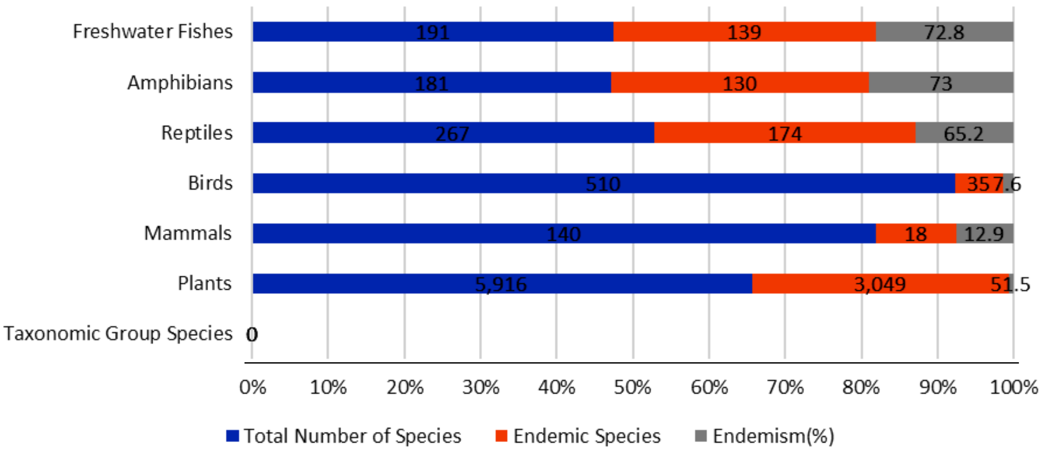

Figure 5. Biological diversity and endemism in the Western Ghats of India and Sri Lanka (Source: www.conservation.org).

The Himalayas comprise of eastern and central Nepal, Bhutan, North-East India (West Bengal, Sikkim, Arunachal Pradesh and Assam), North-West India (Kumaon, Gharwal and northwest Kashmir), northern Pakistan, southeast Tibet and northern Myanmar. The Himalayas are the source of freshwater and store huge amount of water in the form of glaciers so are popularly known as water towers. Mount Everest (8848.86 m), the world highest mountain is located in the Himalayas (Kiran *et al*., 2021). The Himalayan hotspot covers an area 741,706 square kilometers. The climatic and altitudinal variation in Himalayas leads to different types of ecosystems. Total 112,578 km^2 is the are protected under the hotspot out of which 77,739 km^2 is classified as an area of higher level of protection under categories of 1-4 (ENVIS Resource Partner on Biodiversity/ Biodiversity Hotspots: *http://www.bsienvis.nic.in/*). This region supports 163 endangered species (Kiran *et al*., 2021). It is the home of Wild Asian Water Buffalo, One-horned Rhino, Snow Leopard, Musk deer, Himalayan tahr, Blue sheep, Black bear, Chir pheasant, Himalayan monal and Western tragopan. The hotspot consists of 300 mammals, 980 birds, 175 reptiles, 105 amphibians and 269 freshwater fishes (Table 3).

Over 10,000 plant species are present in this biodiversity hotspot out of which 3160 are found nowhere else with 31.6% endemism. In Indian region of Himalayan hotspot over 6000 plant species are found out of which nearly 2000 are endemic. It consists of various plants of great economic value like *Rhododendron*, Bamboo, Orchids, *Cinnamomum*, Pinus, Banana, Citrus, Rice, Ginger, Jute, Sugarcane, Willow etc. (Gupta *et al*., 2020).

Indo-Burma region: Indo-Burma biodiversity hotspot is located in South Asia and covers an area of 2,373,057 square kilometers. From Indian side this hotspot covers an area of North-East India (except Assam) including Andaman and Nicobar Island excluding Himalayan region. Outside India it is primarily located in Southern China, Laos, Vietnam, Cambodia, Thailand (except northern side), and Myanmar (except southern side) (Kano *et al*., 2016). It is one of the most threatened biodiversity hotspots and only five percent of original habitat remaining so it needs primary focus for conservation majors. All the 20 species of endemic primates which are found only in Indo-Burma region are endangered. Indo- Burma biodiversity hotspot shows high diversity due to different types of ecosystems including tropical or sub- tropical dry broadleaf forests, mixed forests, temperate forests, dry evergreen forests, deciduous and mangroves (Basumatary *et al*., 2015). At several places patches of woodlands and shrublands outcrops on karst limestone, scattered forest in coastal areas along with water filled grassland and floodplain swamps are some more distinctive type of vegetation found in this hotspot (Stephan *et al*., 2015). This region is dominated by valuable timber species, Palm trees, Slipper Orchids (33 species), *Rhododendron spp*. etc. Fauna of this hotspot mainly consists of Large-antlered Muntjac, Pangolin (most trafficked animal in the world), Grey-shanked Douc, Leaf Deer, Jullien's golden carp and White-eyed river-martin. This hotspot is a home for many species of plants, animals, amphibians, Aves, freshwater fishes and reptiles (Figure 6).

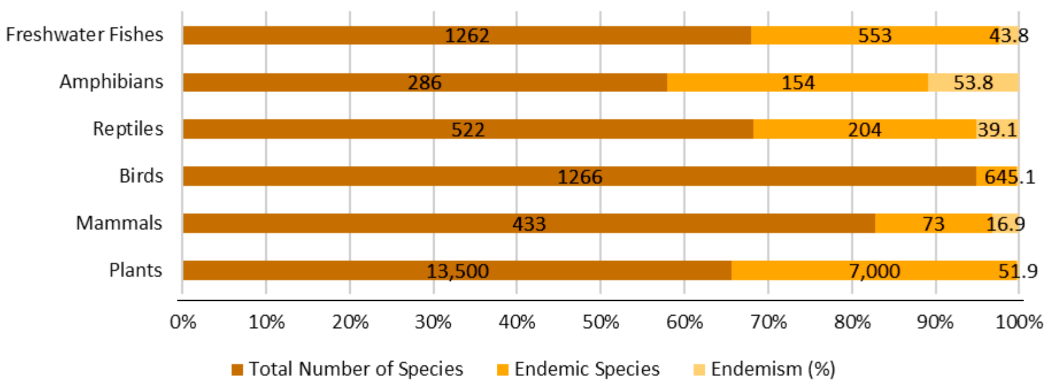

Figure 6. Biological diversity and endemism in the Indo-Burma biodiversity hotspot (Source: bsienvis.nic.in).

The Sundaland: In Pleistocene period, the Sundaland hotspot isolated from mainland Asia as the change in sea level occurs during this period. More than million years ago it was the part of mainland Asia. The Sundaland biodiversity hotspot lies in southeast Asia including, western half of Indonesia, Singapore, Philippines, Brunei, small part of southern Thailand and all part of Nicobar Islands (Indian side). This is extended to an area of over 1,500,000 square kilometres dominated by the largest islands of the world Borneo (third) and Sumatra (sixth) (Verma *et al*., 2020). The Sundaland hotspot characterised by reefs, high mountain terrains, volcanoes, mangroves, alluvial plains, swamps and shallow coastal water. The Sundaland biodiversity hotspot is joined by three other biodiversity hotspots. From northeast it is connected to Philippines hotspot, east side of the Sundaland hotspot is bordering to Wallacea hotspot and Indo-Burma hotspot is joined to the northeast (Hu *et al*., 2021). Sundaland biodiversity hotspot is very rich in biological diversity and it is the home of some of the iconic species like Rhinos, Orangutans (Sumatran and Borneo). It includes different types of ecosystems ranging from high mountain ranges with very less vegetation to low-land rainforests dominated by family Dipterocarpaceae. The other type of forest including mangroves forest, swamp forests, beach forests and sub-alpine forests are also found in this hotspot. The Sundaland biodiversity hotspot consists of more than 50,000 endemic species of plants with 60% endemism. Over 650 species of plants are found in the Nicobar Islands. This hotspot consists of various species, of plants, mammals, birds, reptiles, amphibians and freshwater fishes as shown in Figure 7 with endemism of 60%, 45.3%, 18.5%, 53.8%, 80.3 and 36.8, respectively (Sholihah, 2020).

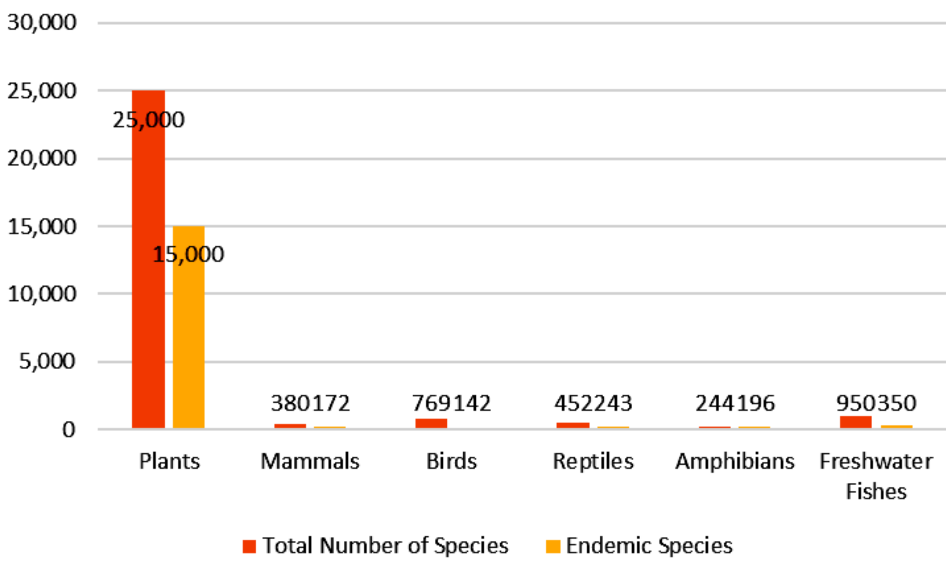

Figure 7. Biological diversity and endemism in the Indo-Burma biodiversity hotspot (Source: www.bsienvis.nic.in; Venkataraman and Sivaperuman, 2018).

Values of biological diversity

Biological diversity plays a very crucial role for the survival of human beings on earth. The humans directly or indirectly depend upon biological diversity for fulfilling almost every need in their life such as food, energy, medicine, housing etc. Biological diversity helps to maintain the ecological balance (Dietsch *et al*., 2016). It provides various ecological services and vital for maintaining, preserving and restoration of various ecological process. Biological diversity is helpful in maintaining biogeochemical cycles, maintaining the flow of water bodies like river and streams all-round the year, soil formation, control in floods, prevention from soil erosion, circulation of air globally and its cleansing, nutrient recycling and life support of all the species. Following are the direct and indirect values of biological diversity (Seddon *et al*., 2016).

Direct values of biological diversity

Consumptive use value: The consumptive use of values includes the direct consumption of resources without passing through the market. Biological diversity provides direct food, shelter, medicines, proteins, enzymes, fats, macro and micro nutrients, beverages, specimens for educational and scientific purposes, tourism and raw material for various commercial purposes (Thapa *et al*., 2020). For example, Aloe Vera is directly consumed for its medicinal properties, timber is used for fire and animals are consumed directly after hunting.

Productive use value: Productive use value is the value which put on marketable products. The different professionals from various fields studies biological diversity for its productive values. The agricultural scientist uses biological diversity for improving the yield and quality of crops. The biotechnologist studies different genetic properties of plants, animals and microbes. The best traits can be selected from the organism with which new improved (disease resistant and high yield) variety of crops can be produced. It also helps to develop better livestock (high nutrient value and fast growth) (Jactel *et al*., 2018). Pharmacist use biological diversity as a raw material for the production of various plants based and animals-based drugs.

Indirect values of biological diversity

Social values: From the ancient time people used to protect biodiversity for their needs. Ancient people used to value biological diversity specially in India, people worship various plants, animals, waterbodies, stones and mountains as they are helpful for their survival and have high esteem. Earlier needs were few as less population so most of biological diversity is conserved (Griffiths *et al*., 2019). Still many tribal people directly depend on forests for their daily needs. Many indigenous people are helpful for conserving biological diversity as they used to cut only old tree branches for wood and only the leaves of young trees are used only for livestock. Modern people are least concerned about the conservation of biological diversity. They only care about their own usage and try to grab it as much as one can at once and exploit it which sometimes leads to irreversible loss (Evers *et al*., 2018).

Ethical and moral values: It is the moral duty of human beings to conserve biological diversity. Planet earth belongs to every species in this world and humans have no right to harm any species if it is of no use to them. Ethical values are related to conservation of biological diversity from animal trafficking, smuggling, illegal activities like cloning, inhuman treatment with animals, biopiracy, unauthorized animal testing, poaching, desertification and uncontrolled deforestation (Antonelli and Perrigo, 2018). To meet the high demand of resources due to population explosion benefits are given more importance rather than ethics and moral values

Aesthetic values: Biological diversity is secret for the beauty of our planet. The different kinds of plants, animals, flowers and birds provide great aesthetic value. Various recreational activities are linked to it like bird watching, butterfly parks, river rafting, national parks, aquarium and botanical gardens (Collins *et al*., 2017).

Economic values: Biological diversity has a great economic value; food is the basic necessity which is the product of it. The agricultural sector, various industries depend upon biodiversity products. The revenue generated from biodiversity products is essential for the growth of any country (Hanley *et al*., 2015).

Scientific values: Various research work has been done on many species of plants, animals, insects etc. and many has to be done to attain knowledge. This scientific knowledge can be utilized for the things which of great value to human beings (Titley *et al*., 2017). During the COVID-19 pandemic we have learned various lessons for conservation of biodiversity. An enzyme used in COVID-19 testing is extracted from a bacterium, *Thermus aquaticus* which was discovered in a geyser in Yellowstone National Park, US (Buchanan, 2021).

Threats and causes of biological diversity loss

Almost every corner on the earth where humans have footprints due to this is everything is under threat. Due to population explosion and cattle heads, the demands for food, water, land and energy increased exponentially. To meet these demands every resource is being exploited. Due to overuse and uncontrolled use of resources and humans induced climate change out of 8 million species nearly 1 million species are under the category threatened and can extinct within decades (UN report, 2019).

The major threats to biological diversity are as follows:

Invasive species: These are the species which are exotic that is not native to a particular place. The introduction of invasive species causes harmful effects on the native species. These have the more potential to adapt and grow due to which the consume the energy and nutrients faster thus threating the local biodiversity. Invasive species are introduced intentionally or by an accident but once they establish itself, they grow very rapidly and other local population of species decline rapidly which can cause extinction (Bailey, 2015).

Climate change: Climate change have huge impact on biodiversity at all the levels. The human induced climate change causes increase in greenhouse gases, global warming, flash floods, changes in precipitation pattern, droughts and many more at much faster rate. All these factors impact biological diversity directly or indirectly. Due to extreme heat the incidents of forest fires are increasing which causes great loss to biodiversity (Stoll-Kleemann and Schmidt, 2017). The life cycle of many plants and animals' species is affected with change in seasons and climate patterns. Many developmental processes of various organism depend upon heat or cold (temperature changes) or the length of day. Due to climate change these cycles and patterns are influenced which can cause extinction of various species and impact abundance, distribution and range of species (Kumar *et al.,* 2009).

Environmental pollution: The environmental pollution is a major threat and primary cause of loss of biological diversity. The air, water, soil, noise and radioactive pollution effects the biodiversity. The industries release various toxins which get mixed into air, water and soil and organisms which consume anything contaminated with it die (Brei *et al*., 2016). The billion tonnes of microplastic particles and plastic products are flowing along with water and it is killing many marine organisms. The noise pollution effects the reproductive patterns of birds. Collectively it is impacting species diversity, weakening ecosystem, impacting food chain and disrupting ecological balance (Gonzalez *et al*., 2016).

Land and sea use change: The use of forest land is done for agricultural purposes and for this forest are cleared. It is the cause for 80% of deforestation. It caused the huge impact in forest ecosystem as it results in habitat loss and degradation. In North America over 3 million birds lost in past 50 years due to habitat loss and pesticides (WWF living Planet Report, 2020). The various wetlands are drained out for land. Oceans are used for various business activities which causes huge impact on marine ecosystem (Oliver and Morecroft, 2014).

Overexploitation: Humans are taking everything in excess and most of it remains unused or wasted. This is causing huge pressure on natural resources as nature is not able to replenish as compared to amount, we are taking from the nature. The species which are of human use are overexploited instead of using it in a sustainable manner. Taking one or few species can cause impacts on other dependent population and it creates ecosystem imbalance. Over fishing is one of the example of species overexploitation and according to a study, all the fishes may extinguish till 2050 (de Souza and Prevedello, 2020).

International Union for Conservation of Nature (IUCN)

International Union for Conservation of Nature (IUCN) was founded in 1948. It is one of the world's largest environmental organizations with more than 1400 member organizations, 200 plus governments and nearly 9000 non-government organizations. Its headquarters are located in Gland, near Geneva, in Switzerland. In 1992, IUCN is given *Official Observer Status* at United Nations General Assembly (Alhajeri and Fourcade, 2019). It is funded by various governments, agencies, corporations and foundations members organisations. IUCN Member Organizations set directions of Union's work and other global conservation efforts in detail, every four years at IUCN World Conservation Congress. IUCN Commissions is a broad network of over ten thousand of scientists and experts. Six commissions are framed by these experts as under:

- Commission on Ecosystem Management
- Commission on Education and Communication
- Commission on Environmental, Economic and Social Policy
- Species Survival Commission
- World Commission on Environmental Law
- World Commission on Protected Area

IUCN Secretariat works on key themes related to conservation, environmental and ecological issues and it is organised into eleven operational regions.

IUCN red list of threatened species

The IUCN red list of threatened species was founded in 1964. It is used to assess the health of various species at the global level. It provides the precise, scientific, quantitative criteria to find out any threat to species that is relevant to most of the species and all the regions of the world.

- Over 134,425 species have been assessed.
- 37,400 plus are classified as threatened with extinction.
- The current target is to assess 160,000 species out of which only 25,575 species remaining.
- The IUCN Red list is updated twice per year.
- The next publication date of the IUCN Red List is 4th or 7th of September, 2021.

IUCN red list categories

Following are the nine categories in IUCN red list (Figure 8).

- **Not Evaluated (NE):** The category of taxon is not decided because the taxon study has not been done.
- **Data Deficient (DD):** The taxon is studied thoroughly but there is less or no information about its distribution and population. Due to deficiency of data, it becomes difficult to decide what category it belongs in.
- **Least Concern (LC):** The taxon is widespread and fairly abundant so no need to place in threatened category.
- **Near Threatened (NT):** The taxon is not in the list of threatened categories but are likely to be included in vulnerable, endangered or critically endangered category in near future.
- **Vulnerable (VU):** Taxon are at the risk for being endangered.
- **Endangered (EN):** Taxon has high risk of extinction in wild.
- **Critically Endangered (CR):** Taxon has extremely high risk of extinction in wild.
- **Extinct in the Wild (EW)**: Known to survive only in captivity, cultivation and or outside natural range.
- **Extinct (EX):** No known individuals of taxon are remaining.

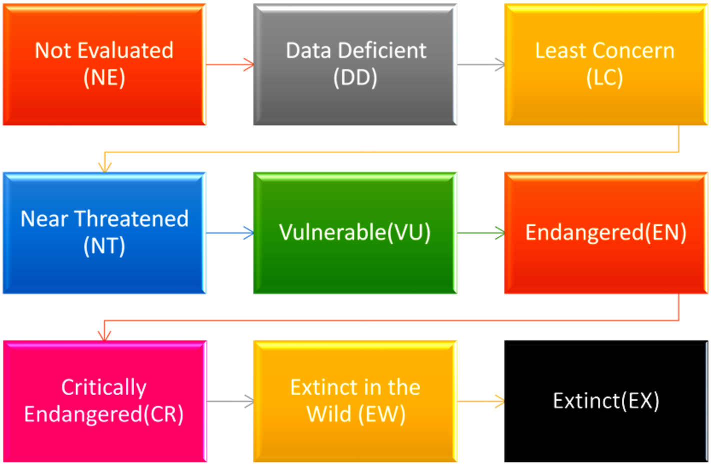

Figure 8. IUCN red list categories.

Conservation of biological diversity

There are two main strategies for conservation of biological diversity (Sayer *et al*., 2021). In Situ Conservation: It means the conservation of species in their natural habitat. For example, National parks, Wildlife sanctuaries, Conservation reserves and Community reserves. Ex Situ Conservation: It means conservation of species or live parts of species outside their natural habitat. E.g., In- Vitro storage, Gene banks, Botanical and Zoological Gardens.

In-situ conservation methods

National parks: In India, currently there are 104 national parks in India (Table 4) covering a region of 43,716 km^2, which is 1.33% of the geographical region of the country (National Wildlife Database, 2020).
Wildlife sanctuaries: Currently there are 566 existing wildlife sanctuaries in India covering an area of 122420 square kilometre which constitutes 3.72% of the geographical area of India (Sahoo and Pradhan, 2021) (Table 5).
Conservation reserves: In India there are about 97 existing Conservation Reserves covering an area of 44483 square kilometres (Table 6).
Community reserves: Currently there are 214 existing Community Reserves in India (Table 7). These community reserves are playing significant role in the conservation of biological diversity (flora and fauna) of the country. In this, Nagaland has the maximum number of community reserves (Puri *et al*., 2019).

Ex-situ conservation method

It is the conservation method in which conservation of plants and animals is done outside their natural

Table 4. State-wise distribution of National Parks, in India (Source: Wildlife Institute of India).

State/ UT	Number of national parks	National park area (km²)
Andhra Pradesh	3	1368.87
Arunachal Pradesh	2	2,290.82
Assam	5	1,977.79
Bihar	1	335.65
Chhattisgarh	3	2,899.08
Goa	1	107.00
Gujarat	4	480.12
Haryana	2	48.25
Himachal Pradesh	5	2,256.28
Jharkhand	1	226.33
Karnataka	5	2,794.05
Kerala	6	558.16
Madhya Pradesh	11	4349.14
Maharashtra	6	1,273.60
Manipur	2	140.00
Meghalaya	2	267.48
Mizoram	2	150.00
Nagaland	1	202.02
Odisha	2	990.70
Punjab	0	0.00
Rajasthan	5	3,947.07
Sikkim	1	1,784.00
Tamil Nadu	5	827.51
Telangana	3	19.62
Tripura	2	36.71
Uttar Pradesh	1	490.00
Uttarakhand	6	4,915.02
West Bengal	6	1,981.48
Andaman & Nicobar	6	1,216.95
Chandigarh	0	0.00
Dadra & Nagar Haveli	0	0.00
Daman & Diu	0	0.00
Delhi	0	0.00
Jammu & Kashmir	4	2432.45
Ladakh	1	3350.00
Lakshadweep	0	0.00
Puducherry	0	0.00
Total	104	43,716

Table 5. State-wise distribution of Wildlife sanctuaries in India (Source: Wildlife Institute of India).

State/UT	Total number of wildlife sanctuaries	Total area (In sq.km.)
Andhra Pradesh	13	8008.49
Arunachal Pradesh	11	7487.75
Assam	18	1840.14
Bihar	12	2901.68
Chhattisgarh	11	3760.28
Goa	6	647.91
Gujarat	23	16574.42
Haryana	8	233.21
Himachal Pradesh	28	6116.1
Jammu &Kashmir	15	10243.11
Jharkhand	11	1955.81
Karnataka	30	6774.81
Kerala	17	1928.24
Madhya Pradesh	25	7958.4
Maharashtra	42	7604.44
Manipur	2	184.81
Meghalaya	4	94.1
Mizoram	8	1090.75
Nagaland	3	20.33
Odisha	19	6969.15
Punjab	13	326.6
Rajasthan	25	5379.26
Sikkim	7	399.1
Tamil Nadu	29	6157.12
Tripura	4	566.93
Uttar Pradesh	25	5828.36
Uttarakhand	7	2690.05
West Bengal	15	1442.12
Telangana	9	7077.72
Andaman and Nicobar Islands	96	389.39
Chandigarh	2	26.01
Dadar & Nagar Haweli	1	92.16
Lakshadweep	1	2.18
Daman & Diu	1	27.82
Delhi	1	0.01
Pondicherry	1	3.9

habitat under special settings in which extra care is done. There are many species of plants and animals which are extinct in wild but are preserved under captivities. Ex-Situ conservation is an important conservation method when In-situ conservation method are not sufficient (Hoban *et al*., 2020). This method has become more advanced now seeds, plantlets, eggs, semen, ovules, embryo, DNA and pollens are preserved by using various techniques. Botanical gardens, zoological parks, field gene banks, tissue culture banks, In vitro and in vivo preservation are some of the examples of ex situ method of biological diversity conservation Perrino and Wagensommer, 2021).

Table 6. State-wise breakup of Conservation Reserve in India (Source: Wildlife Institute of India).

State/UT	No. of conservation reserves	Area (km²)
Gujarat	1	227.00
Himachal Pradesh	3	19.17
Karnataka	14	171.92
Maharashtra	7	490.05
Punjab	4	25.71
Rajasthan	14	655.37
Sikkim	1	0.06
Tamil Nadu	2	4.88
Uttarakhand	4	212.45
West Bengal	5	1415.91
Jammu & Kashmir	32	692.88
Ladakh	5	249.00
Lakshadweep	3	270.05
Total	97	4483

Table 7. State-wise distribution of Community Reserves in India (Source: Wildlife Institute of India).

State/UT	No. of Community Reserves	Area (km²)
Arunachal Pradesh	9	131.60
Haryana	5	115.84
Karnataka	1	3.12
Kerala	1	1.50
Manipur	10	103.72
Meghalaya	71	64.93
Nagaland	114	851.78
Punjab	3	29.02
Total	214	1302

Table 8. Major sites for conservation of biodiversity in India (Source: www.wiienvis.nic.in).

Site name	Total Number
Tiger Reserves	51
Elephant Reserves	32
RAMSAR Wetland Sites	46
Important Coastal and Marine Biodiversity Areas (ICBMs)	107
Important Bird Areas (IBAs)	467
Biosphere Reserves	18
Biodiversity Heritage Sites	18

Zoological Park: It is the open, semi- closed and semi- natural place where animals are kept for the conservation purposes. The animals are provided with proper food, medical care and good hygiene. It is a source of economy as many people visit to see these rare and endangered animals. It is also helpful for research and academic purposes. There are about 147 recognised zoological parks in India (Kumar and Verma, 2017).

Botanical Garden: It is the place where different types of wild and threatened plants are grown or the parts of plants are conserved. It is very helpful for conserving plants diversity. It can be used as a source of economy, scientific research, plant monitoring and a place for biodiversity awareness. The proper care and monitoring of plant species have been done so that species can be re-introduced in their natural habitat. In India, there are about 13 botanical gardens (Baber, 2016).

Seed Banks: These are very helpful for conserving different variety of seeds. Less space is required for conserving seeds and the favourable climate is maintained according to the need and nature of seed. But it is not useful for recalcitrant seeds (Peres, 2016).

Aquarium: It is used to conserve the species which live in water. Many species of fishes, aquatic animals and amphibians are endangered. It is used to provide food, protection and breeding is done so that it can be re- introduced in their natural habitat (Cracknell *et al*., 2016).

In-vivo and In-vitro conservation: These methods of conservation deal with threatened or endangered species and high value species. Here conservation of genes is done by preserving seeds, vegetative propagules, cells and tissue culture. Cryopreservation (in which liquid nitrogen with temperature minus 196 °C) for preservation and gene transforming methods are used in this type of ex situ conservation method (Hiromoto *et al*., 2015).

Sites of conservation importance: Besides this, the biodiversity of India has also been protected through the construction of tiger reserves, elephant reserves, RAMSAR wetland sites, Biosphere reserves, and biodiversity heritage sites that are distributed in the different part of the country. Here is the list of few more important sites of conservation importance with total number of sites present in India (Table 8).

Conclusion

Biological diversity/biodiversity is the variety of lifeforms present on the planet. It is of immense importance for mankind. It provides various ecological services needed by human beings. Also, biodiversity provides us with various things of moral and economical importance. The overexploitation as well as change in the climatic conditions have contributed in the threatening of biodiversity. Moreover, the inappropriate utilization of biodiversity for its commercial value is heading towards its depletion in much faster way. Many ecologically important organisms/plants have become extinct because of their overutilization/overexploitation such as Dodo (*Raphus cucullatus*) and Woolly Mammoth (*Mammuthus primigenius*). Nowadays, many conservation methods like in-situ and ex-situ conservation are being adopted to save the available species especially which are at the verge of extinction. Therefore, this book chapter deals with the values, threats and conservation measured for the biodiversity in an elaborative manner.

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Chapter
[2]

Ethnobotanical studies: Importance and conservation strategies

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Abstract

Plants have given not only for fundamental human needs but also for medical therapy from the beginning of humanity. Their significance, as well as any potential instrumental implications for phytodiversity conservation and modern medicine development, is well acknowledged. Various diseases are becoming more prevalent in many developing countries, and their financial costs are enormous. The majority of people in traditional communities rely on plant-based medications, and traditional health care workers are the primary source of health care. Ethnobotany has long been important in the development of innovative medications, and it is becoming increasingly important in the development of strategies and measures for residual forest conservation and recovery. This rich plant information had been passed down over the generations by tribal people in many sections of the land through word of mouth. Such research is essential to investigate local plants for emerging pharmaceutical enterprises and to strengthen the plant-people relationship in both cultural and ecological contexts to achieve intergenerational equity. This chapter discusses several such studies that have been conducted around the world, as well as on the Indian continent and various conservation measures that can be used to pass on this knowledge of wealth from generation to generation.

Keywords Invasive pest, Legal restriction, Management and status, Natural enemy

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Introduction

Ethnobotanical studies are as old as human civilization itself. Ethnobotany is becoming more essential in applied conservation programmes that consider both social and environmental factors, such as biodiversity and people. The term itself comes from the Greek word Ethnos, which means "people" and botane which means "herb", and includes the study of plants used by primitive communities for food, medicine, religious ceremonies and their spiritual as well as intellectual cultures. American taxonomist and botanist John W. Harshberger established this phrase in 1895 to describe the study of the utilitarian interaction between humans and flora in the environment, including medical purposes (Harshberger, 1896). An ethnobotanist seeks to document local customs including the practical use of plants for a variety of purposes such as medicine, food, and clothing. Indeed a magnificent feature of this discipline is that it is interdisciplinary and borrows theory as well methods from other branches of science *viz*., Anthropology, Linguistics, Botany, Ecology, Nutrition studies and Phytochemistry. Ethnobotanical knowledge of medicinal plants and their use by indigenous societies is useful not only for preserving traditional cultures but also for community health care and drug development (Farooq *et al.,* 2014). Ethnobotanical studies have led to the discovery of many novel drugs. This practice of ethnomedicine is a prominent tool in understanding indigenous communities and their relationship with nature (Anyinam, 1995; Rai and Lalramnghinglova, 2010).

Asia is a very popular global center due to its ancient written traditional knowledge regarding the use of medicinal plant species for treating various ailments as mentioned in Ayurveda, Unani and Chinese traditional system of medicine (Kala *et al.,* 2004). Up to 70,000 plant species are thought to be employed in folk medicine, with the bulk of these species found in the Asia-Pacific region. The two greatest users of medicinal herbs are India and China. Traditionally, India uses about 7,000 medicinal plants species and China uses over 5,000. World Health Organization (WHO) mentioned that about 25% of modern medicines are developed from plants and used traditionally. India has been referred to as the "Medicinal Garden" of the world. Indian Government has developed Traditional Knowledge Digital Library (TKDL) to preserve all types of traditional knowledge like Ayurveda, Unani, Siddha and Yoga. Medicinal plants have demonstrated their contribution to the treatment of diseases such as malaria, HIV/AIDS, diabetes, sickle-cell anaemia, mental disorders (Elujoba *et al.,* 2005) and microbial infections (Okigbo *et al.,* 2005).

Due to low cost and negligible side effects of the traditional system of medicines as compared to the allopathic medicines; the people in developing countries like Bangladesh (90%), Myanmar (85%), India (80%), Nepal (75%), Srilanka (65%), and Indonesia (60%) have strong belief on the traditional health care system. Medicinal plants used by the indigenous people in their traditional health care system provide sources of many important new pharmaceuticals (Balick and Cox, 1996). Therefore, Indigenous knowledge is recognized worldwide, not only because of its intrinsic value but also because it has a potential instrumental value to science and conservation. The investigation of plants and their use is one of the primary concerns and has been practiced by all cultures. Indigenous people with extensive knowledge of medicinal plants remain the ultimate source for retrieving this information for various applications, particularly in modern medicine. Govaerts (2001) reported the existence of 4,20,000 flowering plants from the world. A total of about 50,000 species are used for medicinal purposes (Schippmann *et al*., 2002). In many countries, tribal healers frequently use ethnomedical treatment to treat diabetes, cancer, eczema, jaundice, wounds, scabies, asthma, venereal diseases, aging, skin infection, swelling, snakebite and gastric ulcers, providing information to local people on how to prepare medicine from herbal (Pushpangadan and Atal, 1984; Perumal and Ignacimuthu, 1998).

Medicinal plants and ethnomedicine

Medicinal plants have been reported to contain many chemically active components that can be used to develop novel chemotherapeutic agents. Many newly synthesized drugs have been observed to be originated from natural plant products (Vuorelaa *et al*., 2004). The medicinal property of plants is much more beneficial to cure human as well as livestock ailments. The plant part used, preparation and administration of drugs vary from one place to another (Verma *et al*., 2007). All parts of plants such as leaves, fruits, seeds, bark, roots, flowers etc. are used to treat diseases through various methods. In some cases, the fresh or dried leaves are used while in other cases, the juice extracted from them is used as medicine. Sometimes dried fruits, flowers, roots or bark are used as such and sometimes they are utilized in powdered form. Nowadays, there is a consistent need to evaluate more medicinal plants.

Ethnomedicinal studies in the World

The modern approach to the science of ethnobotany evolved in the USA and a prominent center for the ethnobotanical study is the Botanical Museum of the Harvard University in Massachusetts. Works of Timothy Plowman, Schultes, Gordon Wasson, E. Wade Davis are worth mentioning. Ethnomedicinal studies have been done in various parts throughout the world such as Canada (Uprety *et al*., 2012), Nepal (Singh *et al*., 2012) and Pakistan (Qureshi *et al*., 2007). World Health Organization (WHO) in 2000 recorded over 21,000 plant species for their medicinal uses throughout the world. It has been reported that over 80% of Nigerians depend on herbal medicine (Ugbogu, 2005), as modern health care is still beyond the reach of a good proportion of the rural population. The first-line treatment for 60% of the children with malaria is the use of herbal medicine in Nigeria, Ghana and Zambia. An ethnobotanical survey of 17 communities was conducted in Ogun State, Southwest Nigeria to study herbal medicine used for the treatment of malarial fever (Idowu *et al*., 2010). A total of 38 medicinal plant species were reported to be effective against Malaria. The most commonly used plants were *Morinda lucida, Lawsonia inermis, Citrus medica, Morinda morindiodes* and *Sarcocephalus latifolius*. In Southwestern Nigeria, studies have also been carried out to document the utilization of phytomedicines for the treatment of fevers (Ajaiyeoba *et al*., 2003). Bhat *et al*. (1990) reported the ethnomedicinal use of 52 plant species used by ethnic people of Kwara State, Central Nigeria.

As reported by Kiringe (2005), the use of traditional medicine is prevalent among rural communities of

Africa as they have immense knowledge on ethnomedicine, although this use is rapidly diminishing partly as a result of changes in lifestyle and exposure to western culture. In South Africa, about 80% of the population depends on the traditional health care system. Strong attachment to traditional lifestyle, high level of poverty in the community, remoteness of the area coupled with very poor infrastructure which makes access to modern health facilities difficult which is why people are dependent on traditional medicine. Also, most rural communities of Africa do not see any danger associated with the use of herbal remedies. Initial home treatment of sick persons using herbal remedies is a common practice in African communities (Brown, 1995; Iwu *et al.*, 1993).

About 85% of the rural people of Nepal are said to use herbal remedies. Over 1700 species of plants are commonly practiced in the traditional system of medicine in Nepal (Baral and Kurmi, 2006; Ghimire, 2008). Ethnobotanical studies carried out in the Parbat district of Western Nepal (Malla *et al*., 2015) revealed medicinal use of 132 plant species belonging to 67 families and 99 genera; to cure human ailments like rheumatism, bronchitis, urinary disorders, asthma, dysentery, eczema, gastrointestinal disorders and skin diseases. The herbs were a primary source of medicine (66%) followed by shrubs (20%), trees (11%) and climbers (6%). Bhattarai *et al.* (2005) reported 45 species of medicinal plants belonging to 32 families under 44 genera; the species were found to be useful for the treatment of 34 different ailments in the panchase region in the middle hills of the Nepalese Himalaya. Medicinal plants used by the Tharu tribe of Nepal were studied by Dangoi and Gurang (1991). Thirty-six plant species of 27 families have been documented by Bhattarai (1990) from the Kabhrepalan chock district of Central Nepal. Similar studies on medicinal plants have been carried out in different parts of Nepal by several researchers (Koirala and Khaniya, 2009; Upreti *et al*., 2010; Shrestha *et al*., 2001; Kunwar and Bussmann, 2008; Joshi *et al*., 2011; Acharya and Acharya, 2009; Malla *et al*., 2014).

Ethnomedicinal studies carried out by Barrett (1994) revealed 152 plant species used by the people of Nicaragua's Atlantic coast for the treatment of various diseases. Vidal (1971) investigated the ethnobotany of South East Asia. Ong *et al*. (2011) reported the ethnomedicinal use of 52 plant species used for general health care by the Malay Villagers in Kampung Tanjung Sabtu, Terengganu, Malaysia. The medicinal flora of the central province of Papua New Guinea was reported by Holdsworth and Lacanienta (1980). The herbal health care system of indigenous people of Northern Ethiopia has been documented which was focused on medicinal plant identification, plant part used, disease treated and preparation methods (Mesfin *et al*., 2013). Ethnomedicinal folk drugs used by Bahirdar zuria district of North-western Ethiopia were documented by Raghunathan and Abhay (2009). Vickery (1990), registered 109 ethnomedicinal plants belonging to the Rubiaceae family from London. An ethnobotanical survey conducted by Anderson (1986), reported 121 species used by Akha tribes of Thailand for various diseases and ailments. Ethno-medico-botanical knowledge among the tribal people of Bangladesh was investigated by Rahman (1999). Eighty-one species of medicinally important plants belonging to 73 genera and 37 families were documented (Solangaraarachchi and Perera, 1993) at the tropical dry mixed evergreen forest in Hurula reserve of Sri Lanka. Bhattacharyya (1999) reported the ethnobotanical wealth of the Druk-Yul tribes of Bhutan. Some of the ethnomedicinal plants reported from various parts of the world are listed in Table 1.

Table 1. Some ethnomedicinal plants documented from different parts of the world.

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Reference
Abies spectabilis	Gobre salla, Talish patra	Pinaceae	Leaf needle	Rheumatism, bronchitis, asthma and cold	Malla *et al.* (2015)
Ainsliaea bonatti	Xinyetuer-feng	Asteraceae	Whole plant	Cough, asthma, throat itching	Hong *et al.* (2015)
Annona squamosal	Seetapalam	Annonaceae	Leaf	Tumors	Manjula and Mamidala (2012)
Annona senegalensis	Gwanda, Mufa	Annonaceae	Bark, Root, Leaf	Diarrhoea, constipation, stomach-ache	Adjanohoun *et al.* (1980)
Artemisia afra	Lengana	Asteraceae	Leaves	Prostatitis	Van Wyk and Wink (2004)
Ardisia gigantifolia	Zoumatai	Myrsinaceae	Rhizome, whole plant	Rheumatic arthritis, waist and leg pain, paralysis and traumatic injury	Hong *et al.* (2015)
Asparagus microraphis	Lehonyeli	Asparagaceae	Roots	Period pains	Shale *et al.* (1999)
Cynodon incompletus	Mohloa	Poaceae	Leaves and roots	Labour pains	Watt and Brandwijk (1927)
Desmodium heterocarpon	Bangahat	Fabaceae	Root, leaf	Cough, diarrhoea, skin diseases	Malla *et al.* (2015)
Dichrostachys cinerea	Dundu	Fabaceae	Leaf	Headache	Kankara *et al.* (2015)
Equisetum ramosissimum	Mohlaka-photoane	Equistaceae	Rhizome	Infertility in women	Miller (1997)
Gazania krebsiana	Tsikitlane	Asteraceae	Roots	Sterility in women	Kose *et al.* (2015)
Guiera senegalensis	Sabara	Combretaceae	Leaf	Vomiting, diarrhoea, nausea and general well being	Kankara *et al.* (2015)
Handroanthus impetiginosus	Pau d' arco, lapacho	Bignoniaceae	Bark	Tumor, leukemia	Ochwangi *et al.* (2014)
Helichrysum caespititium	Phate-ea-ngaka	Asteraceae	Whole plant	Increase virility in men	Maliehe (1997)
Lepidagathis incurva	Aaraeuri	Acanthaceae	Leaf, root, bark	Skin cancer	Esha *et al.* (2012)
Lepidium sativum	Zamantarori	Brassicaceae	Leaf	Jaundice	Kankara *et al.* (2015)
Pelargonium sidoides	Khoara	Geraniaceae	Roots	Heartburn in pregnant women	Maliehe (1997)
Polygonatum odoratum	Yu zhu	Asparagaceae	Rhizome	Skin cancers	Wujisguleng *et al.* (2012)

Table 1. Continued...

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Reference
Salvia runcinata	Mosisili	Lamiaceae	Whole plant	Breast cancer, infertility	Kose *et al*. (2015)
Searsia erosa	Tsilabelo	Ebenaceae	Leaves	Uterine cancer	Mogomeri *et al.* (2016)
Ximenia americana	Tsada, Kumhu	Olacaceae	Root, Leaf	Haemorrhoids and dysentery	Ikhiri *et al.* (1984)
Ziziphus mauritiana	Magariya	Rhamnaceae	Root, leaf	Dysentery, stomachache, diarrhoea	Adjanohoun *et al.* (1980); Ikhri *et al*. (1984)

Ethnomedicinal studies in India

India offers a diverse range of medicinal plants that grow in a variety of geographical and ecological situations. There is tremendous scope for the study of ethnobotanical knowledge in India due to the vast heritage of Vedic literature dating back to 2000-1000 B.C. In India, out of 18,864 species of higher plants, over 2000 species are documented and 1,100 species are used in various systems of medicine. According to recent studies by the Ministry of Environment and Forests (MoEF), Government of India, under All India Coordinate Research Project on Ethnobiology (AICRPE), more than 10,000 wild plants are used by the ethnic communities in India in various therapies and miscellaneous uses. Among these, 800 plants are used by the tribal people of India for different medicinal purposes (Dixit and Vakshasya, 2013). A large number of medicinal plants were used by ancient Indians than the natives of any other country of the world and it is evident from the ancient Indian treatises like "Materia Medica" and "Koshas". The Indian Materia Medica alone includes about 2000 drugs of natural origin, almost all of which are derived from different traditional systems and folklore practices (Narayana *et al*., 1998). The first book on Indian ethnobotany was "Glimpses of Ethnobotany" (1981). More than 43% of the total flowering plants in India are of medicinal importance (Pushpangdan, 1995). According to reasonable estimates, 70% of inhabitants in India still rely on herbs (Singh and Gautam, 1997). The traditional system of medicine along with folklore systems continue to serve a large portion of the population, particularly in rural areas of India. In India, considerable research work is being done (Kumar *et al.*, 2010; Murthy, 2012) to document indigenous knowledge.

WHO mentioned that about 25% of modern medicines are developed from plants and used traditionally. India has about 27% of the total known medicinal plant species of the world as it represents one of the most important collection centers (Kumar and Katakam, 2000). The traditional phyto-remedies are socially accepted, economically viable, have a considerable extent of effectiveness and are mostly the only available means. Traditional healers in India use over 2,500 species of plants (Utkarsh *et al.*, 1999). Botanical survey of India initiated recording and documenting the ethnobotanical knowledge of all tribes belonging to the states of Uttaranchal, Andhra Pradesh, Sikkim, Himachal Pradesh, West Bengal, Orissa, Rajasthan, Tripura, Nagaland, Assam, Bihar, Madhya Pradesh, Goa, Arunachal Pradesh, Chhattisgarh, Andaman and Nicobar Island and Jammu and Kashmir.

North-East India posses a rich plant diversity in India and represents one of the biodiversity hotspots of the world (Mao *et al*., 2009). North-East India comprises 8 states representing approximately 8% of the geographical area of the country. The region harbors more than 180 major tribal communities found in India (Sajem *et al*., 2008). Ethnobotany of Miri tribes was reported by Tag and Das (2004) in Arunachal Pradesh. Rethy *et al.* (2010) carried out ethnobotanical studies among the Memba tribe in Dehand-Debang Biosphere Reserve, Arunachal Pradesh. Hynniewta and Kumar (2010) documented hidden traditional knowledge of medicines of the Khasi tribe of Meghalaya. Fifty medicinal plants used by Zealangs were reported by Jamir and Rao (1990). Bhardwaj and Gakhar (2005), studied 17 species of medicinal plants used by tribals of Mizoram. Choudhury *et al.* (2012) reported 53 medicinal plant species used by the Chorei tribe in Assam. Ethnomedicinal studies were carried out by Borah *et al.* (2012) among Mongoloid and Ao-Naga ethnic groups of Disoi Valley forest area of Jorhat district, Northeast Assam and reported 50 species of medicinal plants belonging to 33 families. Traditional Knowledge of the Lotha tribe was documented by Jamir *et al.* (2010) in the Workha district, Nagaland. A total of sixty-six ethnomedicinal plants used by the Phom Naga tribe of Nagaland were reported by Kilangnaron and Jamir (2011). Singh (1990) reported 150 medicinal plants from Manipur. Ashalata *et al.*, (2005) studied the medicinal uses of 120 plant species used for the treatment of rheumatism, bronchitis, ulcers and skin diseases. Forty-one medicinal plants were reported from the Meiti community of Manipur (Singh *et al.*, 1999) used for the treatment of dog bites traditionally. Debbarma *et al.* (2017) conducted an ethnomedicinal survey among the Tripuri tribe in the Mandai area and reported 51 plant species belonging to 32 families to cure a variety of diseases and ailments such as dysentery, cough, jaundice, chickenpox, diabetes, piles, haemorrages, urinary disorders, smallpox, epilepsy, and asthma.

In Southern India, several ethnobotanical studies have been documented by various workers (Abraham, 1981; Nair and Jayakumar, 2003; Hebber *et al.*, 2004; Ayyanar and Ignacimuthu, 2005). Pushpalata *et al.* (1990) studied medicinal plants of Bangalore. Thirty folklore remedies were published by Balu *et al.* (2000) for diabetes in Cauvery Delta. Traditional treatment of leucoderma by Kol tribes of the Vidhyan region of Utter Pradesh was reported by Singh and Narain (2010). Rawat and Pangtey (1987) documented the plants of ethnomedicinal value from the Alpine region of Kumaon, Uttar Pradesh. Ganesan (2004) investigated ethnomedicinal uses of lower plants of Tamil Nadu. In Andhra Pradesh, Vedavathy *et al.* (1991) investigated the medicinal plants used for family planning and birth control. The traditional uses of medicinal plants in the Yanadi tribe were reported by Vedavathy and Mrudula (1996). Bhakshu and Raju (2007) conducted Ethno-medico botanical studies of certain Euphorbiaceous medicinal plants of Eastern Ghats, Andhra Pradesh. Kumar and Pulliah (1998) reported ethnomedicinal uses of some plant species from the Mahbobnagar district of Telangana. The plants used for ethnoveterinary practices by Koyas of Pakhal Wildlife Sanctuary, Warangal district were documented by Murthy *et al*. (2007). Joshi *et al*. (1980) reported folk medicines used by the Dang tribe of Gujrat. The folk medicine used by the Adivasis to treat common women ailments was documented by Ratnam and Raju (2005) in the Eastern Ghats of Andhra Pradesh. Reddy *et al*. (2011)

carried out ethnobotanical studies in the Kadapa district of Andhra Pradesh and provided information on 60 plant species belonging to 33 families. Bhogaonkar and Kadam (2007) reported herbal antidotes used by the Banjara people of the Umerkhed region, Maharastra. Unani uses of some less known folklore plants were reported by Bhogaonkar and Ahmed (2007) in the Amravati district. Kamble *et al.* (2010) studied the plants used traditionally as medicines by the Bhilla tribe of Maharastra. Silja *et al.* (2008) conducted an ethnomedicinal survey in the Wayanad district of Kerala and documented 136 medicinal plant species used by the Mullu kuruma tribe for treatment of bronchial diseases, urinary disorders, kidney stone, anaemia, malaria, tuberculosis, skin disease, inflammation, dandruff, liver diseases, leprosy and burns, epilepsy and leucorrhoea and migraine. Pushpangadan and Atal (1984) carried out ethnobotanical studies in Kerala and reported the uses of 79 plant species by the tribals. Udayan *et al.* (2005) documented 41 plant species belonging to 27 families used by the Kaadar tribe of Sholayar forest of Kerala.

Central India is one of those regions in India where the tribal people and forest dwellers form a considerable part of the population (Jain, 2010; Mishra *et al.*, 2010). Samar *et al.* (2015) reported the ethnomedicinal uses of plants among the Bheel tribe of Guna district of Madhya Pradesh. A total of 32 medicinal plant species belonging to 18 families under 26 genera were documented for different therapeutic uses. Ethnomedicinal uses of plants in Betul district of Madhya Pradesh were documented by Jain *et al.* (2010). Medicinal uses of 25 plant species were reported by Pandey *et al.* (1991) among Baiga tribes of Madhya Pradesh. The medicinal values of 32 plant species were investigated by Verma and Pandey (1990) from district Lohardaga of Bihar. The ethnobotanical plants of the Paharia tribe were studied by Singh *et al.* (1992). Plants of ethnopaedriatic importance were documented by Srivastava and Rout (1994) in the Koraput district of Orissa. Prusti (2007) documented ethnomedicines used by the Bondo tribe in district Malkangri. Ethnobotanical uses of some exotic plants were studied by Chakraborty *et al.* (2003) in the Purulia district of West Bengal. Chaudhury *et al.* (1982) enlisted medicinal plants used traditionally by Jalpaiguri tribes. Kandi *et al.* (2013) documented the medicinal uses of 49 angiospermous plants belonging to 29 families under 45 genera used by the tribals of Nuapada district of Orissa.

Herbal folk medicine in the Northern states of India is commonly practised by herbalists, village traditional healers, elderly persons etc. The Nomadic tribal communities living in the North-West and Trans-Himalaya e.g., Jammu and Kashmir are reputed to have mastered their traditional practice and knowledge of medicinal plants used to treat different diseases (Sharma and Singh, 2006). Jain (1984), carried out ethnomedicinal studies and reported 26 species of medicinal plants from Morni and Kabasar hills in Ambala, Haryana. The ethnomedicinal plants used by the primitive tribes of Rajasthan to treat Venereal and Gynaecological diseases were documented by Joshi (1995). Galav *et al.* (2007) reported the medicinal uses of 33 plant species used in Rajasthan against 20 different diseases of domestic animals. Uttarakhand, lying in the western Himalayan region is famous for its rich variety of herbs and medicinal plants. Medicinal plants used by local vaidyas in the Ukhimath block of Uttarakhand were documented by Semwal *et al.* (2010). The medicinal plants used by the Bhat Community in Punjab for regulation of fertility were studied by Lal and Lata (1980). Kapahi (1990), reported ethnobotanical uses of 50 plant species from Lahaul, Himachal Pradesh. The ethnomedicinal and ecological status of plants in the Garhwal Himalayas were studied by Kumar *et al.* (2011). He studied 57 plants of medicinal importance. Singh (2000), studied plants used by people of Kullu district, North-Western Himalaya.

Kashmir Himalayas, one of the biotic provinces, supports a rich and unique floristic diversity, including a fairly good representation of medicinal plants (Dar *et al*., 2002). Chaurasia *et al.* (2007) in their book entitled "Ethnobotany and Plants of Trans-Himalaya" had documented ethnomedicinal uses of 329 plant species from trans-Himalaya (Ladakh and Lahul-Spiti). Ethno-medicinal uses of 23 plant species were reported by Iqbal *et al.* (2009) from the Pulwama district of South Kashmir. Of the 23 species reported, 10 plant species of 7 families were used by tribal and rural people for treatment of hair ailments and 13 species belonging to 11 families were used for treating boils. The medicinal flora of Shopian, South Kashmir has been recorded by Tantray *et al.* (2009) and a total of 20 important medicinal plant species were documented during the ethnomedicinal survey of the area. A comparative study in the Bhotiya tribal communities of Central Himalaya revealed 86 plant species as being used for treating 37 common ailments (Phondani *et al.,* 2010). Wani *et al.* (2011) reported 32 medicinal plant species from erstwhile, district Anantnag in Southern region of Kashmir Himalayas used by the local people for different ailments. Malik *et al.* (2011) recorded ethnomedicinal uses of 30 plant species from the Kashmir Himalaya. Rashid (2012) reported 28 species of medicinal plants used by Gujjar-Bakkerwal tribal people and other inhabitants of district Rajouri for treating commonly encountered gastrointestinal disorders like diarrhoea, indigestion, stomach pains, dysentery, dyspepsia and vomiting. Jeelani *et al.* (2013) conducted an ethnobotanical survey and documented 38 medicinal plant species from much higher altitude hilly and tribal areas of Kashmir Himalaya. Most of these medicinal plants were herbs and used by the rural and tribal people for the treatment of various diseases and ailments such as cough, skin diseases, wound healing, gastric disorders etc. Lone *et al.* (2013) surveyed some rural areas of the Bandipora district of Jammu and Kashmir and documented 25 species of medicinal plants used by the local people to cure various human and livestock ailments. Rinchen and Pant (2014) reported the ethnopharmacological significance of 68 plant species used by the inhabitants surrounding Suru and Zanskar Valleys of cold desert, Ladakh. These medicinal species were used for curing various ailments / sexual dysfunctions such as antispasmodic, aphrodisiac, rheumatism, blood purification, pulmonary problems, liver disorders, malaria, kidney stones etc. The ethnomedicinal plants of Shankaracharya Hill in the Srinagar district of Jammu & Kashmir were studied by Kumar *et al.* (2015a) and reported 130 medicinal plant species.

The medicinal plants used by the tribal communities of Bangus Valley of North Kashmir were reported by Ishtiyak and Hussain (2017). Their study revealed ethnomedicinal uses of 75 plant species that were used as traditional medicine by Gujjar communities for curing several diseases in the area. Mir *et al.* (2017) surveyed *Betula utilis* forest in Sind Forest Division (Sonamarg) and Tangmarg Forest Division (Gulmarg) and reported ethnomedicinal utilization of 21 plant species used by rural communities of Northern and Central regions of Kashmir Himalayas. Eighty-three medicinal plant species were recorded by Bhat *et al.* (2018) that were used by tribal and local people of Bandipora for treating diabetes, cholera, scabies, typhoid, whooping cough, fever, blood purification, respiratory problems, joint pains, urinary disorders, stomach ulcers etc. Recently, Fayaz *et al.* (2019) conducted an ethnobotanical survey in Daksum Forest of Anantnag district of Jammu and Kashmir State reported 108 plant species of ethnomedicinal importance. Various other ethnomedicinal studies in Kashmir were carried out by different researchers such as Khan *et al.* (2004); Ishtiyak *et al.* (2010); and Yousuf *et al.* (2012). Some of the ethnomedicinal plants reported from various parts of India are listed in Table 2.

Table 2. Some ethnomedicinal plants documented from different parts of India

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Refrences
Achillea millifolium	Berguer	Asteraceae	Whole herb	Snakebites	Malik *et al.* (2011)
Aconitum heterophyllum	Atis, Paewakh	Rananculaceae	Root	Arthritis, throat infection, stomach ache, dyspepsia, Skin bites	Kumar *et al.* (2016); Khan *et al.* (2004)
Adiantum capillus-veneris	Guentheer	Pteridaceae	Leaves	Chest congestion, headache	Dar *et al.* (2018)
Ajuga bracteosa	Jan-e-adam	Lamiaceae	Whole plant	Lice killer	Hassan *et al.* (2013)
Angelica gluca	Chohore	Apiaceae	Roots	Gastrointestinal disorders	Ishtiyak and Hussain (2017)
Albizzia lebbek	Kala siris	Fabaceae	Whole plant	Asthma, leucoderma, cough and cold, wounds, snake bites	Samar *et al.* (2015)
Althea rosea	Suzposh	Malvaceae	Whole plant	Jaundice, urinary irritation, swelling, kidney pain, dandruff	Lone *et al.* (2015)
Artemisia maritima	Murin, Moori	Asteraceae	Shoots, leaves, seeds	Intermittent fever, intestinal worms, abscesses	Kumar *et al.* (2015b)
Asparagus racemosus	Sathavari	Liliaceae	Leaf, rhizome	Leucorrhoea, stomach ache, epilepsy	Silja *et al.* (2008)
Bauhinia purpurea	Chingthrou	Caesalpinaceae	Bark	Leucorrhoea, menstrual disorders and poisonous bites	Khumbongmayum *et al.* (2005)
Berberis ulicina	Sinskingnama	Berberidaceae	Fruits	Ringworm	Buth and Navchoo (1988)
Bergenia ciliate	Zakhmihyat/ palpati	Saxifragaceae	Roots and leaves	Headache, diarrhoea, weakness, fever and wounds	Lone *et al.* (2015)
Bidens pilosa	Bhojpatar	Asteraceae	Leaves	Blood clotting of wounds	Akhtar *et al.* (2018)

Table 2. Continued...

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Refrences
Brassica oleracea	Haakh	Brassicaceae	Leaves	Corns, constipation	Kanta *et al.* (2018)
Butea monosperma	Palash	Fabaceae	Bark, gum, leaf, flower, seed, resin, stem	Snake bites	Jeetendra and Kumar (2012)
Calotropis procera	Madar	Asclepediaceae	Whole plant, branches, flowers, leaves, latex	Cough	Samar *et al.* (2015)
Cannabis sativa	Bhang	Cannabinaceae	Stem, leaves	Diarrhoea, skin diseases, rehematism, cholera, wormicide	Samar *et al.* (2015)
Cassia fistula	Amaltash	Caesalpinaceae	Seed, stem, roots, fruit, pulp, bark	Snake bites	Jeetendra and Kumar (2012)
Cedrus deodara	Deodar	Pinaceae	Leaves, bark, root	Stomach disease, rheumatism, diabetes	Kumar *et al.* (2019)
Clematis gouriana	Eruvalli	Rananculaceae	Leaf, root	Rheumatism, cough	Silja *et al.* (2008)
Colchicum luteum	Whiri-kiumposh	Colchicaceae	Bulb	Spleen, liver disorders	Ishtiyak and Hussain (2017)
Corydalis govaniana	Sangi-harb	Fumariaceae	Roots and flowers	Headache	Jeelani *et al.* (2013)
Curcuma longa	Haldi	Zingiberaceae	Rhizome	Skin disease, wounds, fracture	Tiwari and Pandey (2010)
Cydonia oblonga	Bumchu-ont	Rosaceae	Fruits, seeds and flower	Cough, chest pains, constipation, fever, general body weakness, birth problems	Fayaz *et al.* (2019)
Cyperus rotundus	Sengban	Cyperaceae	Rhizome, tuber	Dyspepsia, fever, cough and bowel irritation	Khumbongmayum *et al.* (2005)
Daucus carota	Mo-harmunj Ghasa	Apiaceae	Roots	Digestive disorders, fatigue	Lone *et al.* (2015)
Dioscorea bulbifera	Genthi	Dioscoreaceae	Stem, leaf, tuber	Lung bleeding, eye disorder, syphilis, goitre	Ghosh *et al.* (2015)

Table 2. Continued...

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Refrences
Euphorbia helioscopia	Gur sotsul, Gursuchel	Euphorbiaceae	Seeds, roots, latex	Diaphoretic, fungal infections, warts, expulsion of intestinal worms	Kumar *et al.* (2015)
Ficus carica	Fig	Moraceae	Fruit	Cough, cardiovascular disorders, loss of apetite, indigestion, bronchial problems,	Mawa *et al.* (2013)
Ficus religiosa	Pipal	Moraceae	Leaf, fruit, root, bark	Gonorrhoea, migraine, diabetes, epilepsy, leucorrhoea, liver diseases	Singh *et al.* (2011)
Gallium aparine	Kanchari	Rubiaceae	Whole herb	Skin redness and allergies	Sarad *et al.* (2017)
Glycine max	Kala bhatt	Paplionaceae	Seed	Diabetes, menstrual disorders	Shah (2014)
Murraya koenigii	Karipatta	Rutaceae	Leaf	Vomiting, inflammation, itching and bites of poisonous animals	Handral *et al.* (2012)
Nelumbo nucifera	Thamara	Nelumbonaceae	Flower	Piles	Silja *et al.* (2008)
Nepata ciliaris	Nueet	Lamiaceae	Whole plant	Fever, cold, respiratory disorders	Gautam *et al.* (2012)
Oxalis corniculata	Bhilmoru	Oxalidaceae	Whole plant	Dysmenorrhoea, hepatitis, diarrhoea, dysentery	Kaur *et al.* (2017)
Perilla frutescens	Bhangjeer	Lamiaceae	Seed, leaf	Asthma, depression, chronic bronchitis	Bachheti *et al.* (2014)
Podophyllum hexandrum	Wunwangun	Podophyllaceae	Fruits, leaves and roots	Skin diseases, gastric problems	Jeelani *et al.* (2013)
Prunella vulgaris	Kulvaeth	Lamiaceae	Whole plant, leaves	Rheumatism, body pains	Hassan *et al.* (2013)
Rosa webbiana	Shal martchwa ngan	Rosaceae	Flowers and fruits	Stomach pain, cholesterol level, digestive disorders, joint pains	Dar *et al.* (2018)
Ricinus communis	Arandi	Euphorbiaceae	Whole plant	Headache, fever	Samar *et al.* (2015)
Salix disperma	Kankori	Salicaceae	Fruit, bark	Heart problem and eye disorders	Sarad *et al.* (2017)

Table 2. Continued...

Scientific name	Vernacular name	Family	Part(s) used	Medicinal use	Refrences
Salix wallichiana	Dan-thiveer	Salicaceae	Leaves	Fever and general body pain	Fayaz *et al.* (2019)
Scutellaria discolour	Yenakhat	Lamiaceae	Whole plant	Menstrual disorders, injuries, cuts and wounds	Khumbongmayum *et al.* (2005)
Sorghum halepense	Durham	Poaceae	Seeds	Diuretic	Akhtar *et al.* (2018)
Thespesia populnea	Poovarasu	Malvaceae	Leaf	Abscesses	Silja *et al.* (2008)
Thymus serphyllum	Jawand	Lamiaceae	Seeds and leaves	Skin eruptions, baldness, worm infections	Malik *et al.* (2011)
Urtica dioica	Soii	Urticaceae	Leaves, roots	Rheumatism	Kanta *et al.* (2018)
Viscum album	Aal	Loranthaceae	Whole plant	Fractures, laxative	Khan *et al.* (2004)

The importance of ethnobotanical flora and conservational strategies

Our world has great biological diversity and in some areas, diversity in its natural state will be more valuable than when we use it for timber or grazing. The ethnomedicinally derived compounds show greater potential for the development of products. Despite the ancient nature of traditions, medicinal plants still form the basis of traditional or indigenous health care systems; and are being still used by the majority of populations throughout the world (Dar *et al.*, 2018). About 80% of the world population in the rural areas of developing countries depend on herbal medicine for their health needs (World Health Organization, 2000). Many economic benefits can be provided by the development of indigenous medicines and the use of medicinal plants for the treatment of various diseases (Azaizeh *et al.*, 2003).

Socio-economic impacts on ethnobotanically significant plants are very high and deserve more exploration. This also highlights the need to re-evaluate the possible retrieval from pressure exerted on natural vegetation especially due to overgrazing, over-collection, and developmental activities such as urbanization, and industrial oil polluting activities. Special emphasis is required to study the impact oil -polluting activities, have on the natural vegetation and how these activities might be changing the species composition in different areas. Further degeneration of natural vegetation cover can be prevented by effective grazing management plans and it would allow recovery of damaged ecosystems as well. Medicinal preparations derived from natural sources, especially from plants, have been widely used in various cultures for time immemorial. There is a critical need to document precious traditional knowledge owned by the local communities of various parts of our country as well as abroad. Efforts should not be focussed only on the traditional ethnomedicinal applications, but also on all the ethnobotanical uses, practices and interactions of local inhabitants with the natural ecosystems. Proper documentation of traditional knowledge can ensure sustainability and availability of this knowledge to future generations. Also, we are in pressing need of scientific validation of this knowledge particularly those practices related to health care. Conservation efforts need to be focused on species-rich habitats. There is a need for protecting habitats especially those habitats which harbor rare and very rare species of high conservation value as well as ethnobotanical significance. Special conservation measures are recommended for protecting the populations of the endangered and rare species in the area such as those of the endemic and a near-endemic. Priority should be given to the valuable plant species for conservation initiatives, which will account for both ethnobotanical and conservation importance of species. In addition to this, any direct, human-induced assault on nature resulting in loss of local flora, ethnobotanically significant plants may also face other threats such as global warming and climate change. Future studies need to be focussed on assessing the combined impact of natural changes, particularly climate and human-induced impacts that influence native plants in the region.

Conclusion

The Knowledge of the medicinal uses of plants has been transmitted from one generation to the next orally. It is mandatory to document the knowledge from the local people before the knowledge will drain off. The need to conserve these plants and this traditional knowledge is of utmost importance because if necessary conservation measures are not taken at the earliest, the day will not be far when these God-gifted resources will be depleted completely from their natural habitat. There is an urgent need of conserving medicinal plants so that in future the coming generation could benefit from these precious plants that are a real gift of nature for the mankind.

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Chapter
[3]

Weeds biodiversity: Challenges and opportunity in current context

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Abstract

In agro-ecosystems, different crops have a strong connection to biodiversity in the landscape. Weed density and behaviour pattern in our eco-system directly influence crop cultivation aspect. Weed biodiversity play a significant function in maintaining the processes and functions of ecosystems, including farming. Changes in climatic factors would alter the nature of vegetation and agriculture and it is true especially with the increasing atmospheric CO_2 concentration. While the variability in plant responses is large, C3 weeds generally increased their biological yield and LAI, under higher CO_2 concentrations compared with C4 weeds. However, the feasibility of crop pattern should be assessed not only in terms of crop yield but also adequate levels of biodiversity within cropland. Agricultural practices, which vary according to local climate, cause a disturbance to the agro-ecosystem, and change the dynamics of the weed community, creating ecological niches. Weed biodiversity plays a key role in supporting food webs and ecosystem services in agro-ecosystems. Weed miscellany provide ecosystem services for the upper trophic levels in crop land ecosystems. Pattern of distribution of the weed community (abundance and richness) are often difficult to predict so monitoring changes is recognized as crucial both in stable and unstable environments.

Keywords Biodiversity, Climate change, Ecology, Weed, Yield

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Introduction

Agriculture in India is facing several challenges which together are manifested into the sustainability issues. Changing in climate due to human intervention and other modern tool, aggravated the situation. The broad contours of the agricultural production system in the country have been defined by the need to achieve food security which calls for close attention. Day by day many unused plants, which earlier called as weed become get paramount important in modern medicine and day to day as food ingredient (Mukherjee, 2021). During the past few years, alteration of weather parameter has induced transformation in the weed distribution pattern in cultivated and non cultivated crop ecosystems throughout the world. Variation in climate distribution pattern from forest to terrestrial land gave different kind of environment to weed growth and development (Mukherjee, 2020a). Climate transform leads to three different patterns of transform occurred at diverse scale: (1) array shifts at the landscape scale, (2) niche shifts at the community scale, and (3) trait shifts of individual species at the population scale. Weeds are the part of dynamic ecosystems, start off in ordinary environment and become obstacle to the crops and change its pattern of appearance under slight weather change or modification (Mukheree, 2005). Weeds are a major biotic constraint limiting agricultural production. The problem is not only location-specific but also highly dynamic. With the globalization, invasive weeds menace may increase and some time reduced crop quality and economic value. Invasion of different weed species become threat and challenge to ecosystem, environment and social structure of our planet. It is measured as one of the most significant drivers of biodiversity loss and inhabitant genus endangerment and extinction. Rigorous monitoring through extensive surveys to detect invasive weeds, taking strict quarantine measures, evolving effective management strategies for containing the entrance and spread and preventing the losses caused by the invasive exotic weeds (e.g.: *Ambrosia trifida*, *Cenchrus tribuloides*, *Cynoglossum officinale*, *Chromolaena odorata*, *Eichhornia crassipes*, *Lantana camara*, *Parthenium hysterophorus*, *Mikania micrantha*, *Phalaris minor*, *Savlinia molesta*, *Solanum carolinense*, *Viola arvensis* and others) are essential. The efforts for managing weeds are going on since time immemorial, due to this we lose many of the important weed species and ultimately loose various diversity pattern of weeds. Further, the so-called modern cultivation practices, which involve extensive tillage and utilization of various inputs like seeds, irrigation water, organic manures, synthetic fertilizers and other agro-chemicals, are also leading to increased weed infestation and some places we found weed shifting. The threats posed by herbicide-resistance development in weeds, globalization and introduction of alien invasive weeds, and climate change favouring intense crop-weed competition are also a major concern. Despite the development of effective weed management technologies and their adoption on large areas throughout the country, there is a need for continuous monitoring and refinement of strategies in order to lessen the adverse effect on agricultural productivity, environment and biodiversity.

Association of weeds with different cropping system is sometime beneficial and harmful to the crop (Mukherjee, 2021). Various evidence revealed that, weed flora have changed over the past century, with some species declining in abundance, whereas others have increased mainly due to alteration of environment. Various evidence revealed that decline in the size of arable weed seed banks due to erratic or less rainfall pattern. Some of these changes reflect improved agricultural efficiency, changes to more intensive crop rotations and the use of more broad-spectrum herbicide combinations, which also affect our environment and socioeconomic status of farmer's. Interrogation of a database of records of phytophagous insects associated with plant species reveals that various weed group support a high diversity of insect species and under sling change of environment their insect micro-habitat will be changed. Reductions in abundances of host plants may affect associated insects and other taxa. A number of insect groups and farmland birds have shown marked population declines over the past four decades (Leon *et al*., 2017).

Soil texture and its pattern depend on intensity of rainfall and other factors which are directly related to our environment and influence distribution of weed distribution pattern and its ecosystem (Singh *et al*., 2003). Diverse ecosystems had to make room for monocultures of single crops, intensively managed with chemical pesticides. This leads to herbicide resistant weeds problem. During the era of high tech modern industrialized agriculture, with the use of intensive agro-input in nano form, we face challenge of different pest and disease. Some microbes, insects and weeds developed a resistance to the chemicals. So-called "super-weeds" and other pests remained untouched by the rain of pesticides (which happens naturally when one "weapon", in this case weed killers, is used too intensively). Intensive chemical input leads to pest become resistance and use of various pesticides becomes useless and we are in real trouble. Because now we have populations of super-adapted pests and a "weapon" that's rendered completely useless! And this phenomenon is happening more and more often in agriculture. which leads to lose of biodiversity.

Weeds associated with crops

Major weeds associated with different crops vary with crops and locations. Various works revealed that (a) infestations of little mallow (*Malva parviflora*), jangli palak (*Rumex retroflexus*), annual bluegrass *(Poa annua*), lessers wine cress (*Coronopus didymus)* and rabbit foot polypogon (*Polypogon monspliensis*) are increasing in the rice-wheat cropping zone; (b) tiger foot morning glory (*Ipomoea pestigridis*) has become a serious weed of sugarcane in Haryana and Uttaranchal; (c) the intensity of submerged weeds is gradually increasing in the rice-rice sequence in Assam; (d) ragweed (*Ambrosia artemisiifolia*) and parthenium (*Parthenium hysterophorus*) are gradually spreading beyond the non-cropped area and entering cropped and plantation areas; and (e) loranthus (*Loranthus longiflorus*) is likely to be a major problem for mango orchards in the southern part of the country. In addition, weedy rice (*Oryza sativa*.) is emerging as a major problem in direct-seeded rice.

Aquatic weed

Aquatic weeds are more scientifically termed as aquatic macrophytes. These have beneficial effect as well as harmful effect based on its utility pattern in our day-to-day practice. Few aquatic plant acts as a pillar of mineral recycling with their various enzymatic metabolic action. Aquatic plants are an essential component of aquatic ecosystems, and as some of them may reach excessive proportions they pose a serious threat to fishery industry. Aquatic weeds compete with fish for water, nutrients, light, niche and oxygen, and thus reduce fish yields. The major aquatic weed species such as water hyacinth, bullrush (*Typha angustata*), homwort (*Ceratophyllum demersum*), salvinia (*Salvinia molesta*), lotus (*Nelumbo nuciferct*), alligator weed (*Altemanthera philoxeroides*), *Hydrilla verticillata*, *Vallisneria spiralis, Chara* sp., *Nitella* sp. and *Potamogeton* sp. are a primary concern in India (Kumar, 2011). The aquatic weed problems vary from one state to the other. For example, the major aquatic weeds in Kerala include water hyacinth, *Salvinia* sp., *E. crassipes*, *Pistia stratiotes*, *Altemanthera* sp., *Azolla* and *Lemna minor* (Jayan and Sathyanathan, 2012). In Madhya Pradesh, predominant aquatic weeds include *Vallisneria* sp., *Potamogeton* sp., *Ipomoea* sp., *Lemna* sp., *Azolla* sp., *Pistia* sp., *Hydrilla* sp., *Chara* sp. and *Myriophyllum* sp. (Singh and Nigam, 2014). Management of aquatic weeds become very challenging due to complicated soil-water ecosystem. Scientist mainly focused on minimized weed seed bank and support only to the level of biological diversity within the crop. Aquatic weeds can be used as source of mulching and fertilizer in number of crop field. Utilization of various end product of unwanted plant tissue in compost form help in soil mineralization and act as an effective source of natural fertilizer under different crop sequence. Best use of aquatic weeds for horticulture would be to apply them as a thick layer (as mulch) in different plantation and orchard field, on the soil to suppress weeds, conserve moisture and restore soil fertility.

Crop-weed association

Different kind of weeds associate in different way to different crop based on their behavioural pattern and mimicry. Some weed association with crop depend on few aspect, these area mainly as:

Morphological similarity: Under different field condition few of the weeds species (*Echinochloa crusgalli* , *Phalaris minor* etc.) are quite similar to main crop (rice, wheat etc.). Morphological alike weed be complicated to manage both by chemical (herbicide etc.) and mechanical measures. As we saw rice crop looks alike with *Echinochloa crusgalli, as* rice uprooted for transplanting in main field, this weeds also enter with rice seedling into main field and grow simultaneously with the crop, and compete with plant for light, nutrient and water. This can be very difficult to control with normal herbicide as our rice crop will also suffer.

Seed shedding behaviour: Number of unwanted plants complete their life cycle prior to the harvest of main crop in the field in which they are associated. The seeds which are drop in the field during one season, become the basis of invasion during the next crop season. Nearly 65-72 % seeds of problematic weeds such as *Avena ludoviciana, Ischaemum rugosum Phalaris minor, Trianthema portulacastrum* and *Echinochloa crusgalli* are drop in the same field. Behavioural pattern of seed shedding is one of the main reasons of alliance of a specific weed with a particular crop when sown on same field regularly.

Seed separation problem: Few plant seeds are quite similar to the seed of few obnoxious weeds, and they cannot be separate from crop seed, even they easily pass-out from the sieving during post harvest management. Such weed seeds easily escape from seed separation and are sown with crop seed during seed sowing in field. For example, *Rumex spinosus, Avena ludoviciana, Convolvulus arvensis* etc. seed size and shape are quite similar to wheat seed and these cannot be separate out even through sieve. The harvested produce swamped with such unwanted plant seeds must be kept away from seed production programme.

Friendly milieu: Weeds association with different crop not only depends on cropping pattern but it also influenced by crop behaviour in particular environment. This can be easily understood as in field condition *Avena ludoviciana* (wild oats) infestation in wheat crop can be checked through wheat-rice rotation for 3 to 4 years. Seeds of *Avena ludoviciana* are porous in nature, and soak up water and loose feasibility under constant standing condition (water). The nonstop wet situation gets rid of wild oats but could provide support to *Phalaris minor* establishment due to pleasant ecological situation formed with the promotion of paddy cultivation.

Germination in flush: Seed germination pattern of various weed species vary, and some seed germinate with number of flushes and become very tough to control them because of irregular behaviour of seeds. During field condition we found that few weeds germinate just after application of herbicide (resistant nature) and become very difficult to control in rest part of crop life cycle, even though under good crop management practice. For instance, *Phalaris minor* seeds sprout in numerous flushes in wheat crop and owing to this feature it is very hard to manage this weed.

Dominance of single set of weedicides: Age old herbicide or continuation application of same nature of herbicide or weedicide led to resistance feature in plant (weed). For example, due to single application of isoproturon for long time leads to *Phalaris minor* resistant in wheat field (Punjab, Haryana and Uttar Pradesh). Even though application of high dose of isoproturon could not curb the problem of *Phalaris minor*. So, this plant continued to grow with wheat by physiological change. Mixed application of different herbicide or rotational utilize of chemical control measures, helps a lot to evade alliance of a specific weed with a particular crop.

Weed utilization

For considerable time, the utilization of weeds uprooted from farm crops has been largely confined to their consumption as (i) green (leafy vegetables), (ii) animal forage, (iii) medicinal plants, and (iv) compost material. Their utilization as greens is a specific species–based activity with weeds like *Chenopodium album, Amaranthus viridis, Commelina benghalensis, Rumex spp*. and *Portulaca spp*., which are consumed, sometimes, in urban areas as a delicacy. But there is no denying fact that it is an extra micro –dimension utilization of weeds vis-a-vis tons of weeds that invade each hectare of crop land (when neglected). The utilization of weeds as forage for mulch animals involves consumption of mixed growth of varied weed species collected from neglected crop fields. Strange enough, this recommendation has been made by some scientists without reporting any critical analysis of individual weed species, particularly in respect of their alkaloid contents. It is a common observation that animals fed on either weeds or weedy forages, often yield tainted and foul-smelling milk and meat. That is why utilization of weeds for animal feed has not been accepted extensively. Regarding the medicinal uses of certain weed species, it may be useful to note that no doubt several weed species occurring on crop lands (and other places) possess certain very useful medicinal constituents, but manufacturers of plant medicines do not use these weeds for the purpose. They, in fact, cultivate the very same plant species separately, under best cultivation care on their medicinal farms as medicinal crops. Sometimes, the mixed growth of weeds uprooted from neglected farm crop fields is attempted to be utilized for composting on farms. However, the idea is beset with survival of many live weed seeds, thus compost disseminates many weed seeds throughout the crop fields. That is why the crop fields treated with FYM/ arid compost are found to be weedier than the urea and like synthetic fertilizer treated plots. Over and above the analysis of various modes of utilization of weeds presented so far, the fundamental issue is whether we want to grow crops or weeds on our farmlands (Figure 1a-1h). Weed utilized in number of ways according to their suitability for a particular community such as:

Utilization of weeds from non-crop lands and water bodies

Tons of weeds infest our grazing lands, plantations, National Parks and large waterbodies. And these grow by leaps and bounds each day, covering more and more area. On an average, it is observed that such weeds add 1–2 t/ha of biomass everyday. Water hyacinth (*Eichhorrnia crassipes*) is the oldest example of such a weed in water bodies throughout India. Among the terrestrial weeds, *Lantana camara* in northern India and *Mimosa*, *Mikania*, *Chromolaena*and *Solanum spps*. in southern India are of immediate concern. Unfortunately, no control measure (chemical, biological or physical) of the above weeds has been found feasible so far and these weeds continue to grow and expand fast. Their control by utilization is a good proposition, provided we are talking of their bulk or mass utilization which could be capable to outsmart their average per day growth rates started earlier. Insignificant utilization methods of such gigantic weeds often reported in literature, like thatching and furniture material, cannot be helpful in recovering our wasted lands and water bodies. A rapid, extensive and economical method of composting of terrestrial and aquatic weeds is an attractive proposition for their management in near future. Intensive research is, however, required in this respect, jointly by the agronomists, microbiologists and biotechnologists. Weed composting become very easy under control condition with proper technical guidance.

Weeds as medicinal plant

Various medicinal plant, which were earlier treated as weeds, become now valuable herbs and used as impotent medicinal plant (Mukherjee, 2008). Studies revealed that, few plant become very important for many community as medicinal plant (Table 1 and 2) such as: *Aconitum ferox, Acorus calamus, Artemisia vulgaris, Astilbe rivularis, Bergenia ciliate, Cephaelis ipecacuanha*, *Ceritella asiatica, Clematis buchanaria, Dioscorea composite, Dichroa febrifuga*, *Drymaria diandra, Digitalis purpurea* , *Eupatorium cannabinum, Ficus semicordatus, Fraxinus floribunda, Gentiana kurro, Heracleum wallichii, Litsaea cubeba, Nardostachys grandiflora, Oroxylum indicum, Panax pseudo-ginseng, Paederia foetida, Phytolacca acinosa, Picrorhiza kurrooa, Podophylum hexandrum, Przewalski atangutica, Pteris biaurita, Rheum modi, Rhus semialata, Rumex nepalensis, Swertia chirata, Thysamolaena maxima, Urtica dioica, Viscum articulatum, Valeriana officinalis* (Mukherjee, 2014a).Our field observation revealed that, Darjeeling range ($87^0 59'$ - $88^0 53'$E and $28^0 31'$-

Table 1. List of plant which has high medicinal value.

S. No.	Scientific name
1	*Alsophila costularis* Bak
2	*Angiopteris evacta* Forst
3	*Aralia sikkimensis* Parry
4	*Cinnamomum tamala* Nees & Ebern
5	*Cinnamomum obtusifolium* Nees
6.	*Dioscorea deltoidea Wall ex Kunth.*Thunb
7	*Gloriosa superba* Linn
8	*Pinus roxburghii* Sargent
9	*Rauvolfia serpentina* Benth ex Kurtz
10	*Swertia chirata* Buch Ham.
11	*Taxus baccata* Linn

Table 2. Potential impacts of climate change on weeds significant to agriculture (Source: Australian Module, 2008).

Common name	Scientific name	Expect impact
Blackberry	*Rubus fruticosus*	Expected to grow towards south wards in high altitudes range, because it is sensitive to more temperature and drought
Chilean needle grass	*Nassella neesiana* (Trin. & Rupr.) Barkworth	Expected to increase its ranges because it highly invasive (long lived, seed dispersal by wind andwater) and drought tolerant.
Gorse	*Ulex europaeus*	Expected to retreated southwards because it is drought sensitive.
Lantana	*Lantana camara*	Expected to continue its moves southwards into high rainfall zone of northern new south wales.
Mesquite	*Prosopis glandulosa*	Some risk that it may move into lower rainfall areas because it is very drought tolerant.
Parthenium	*Parthenium hysterophorus*	Not suited to winter dominant rainfall areas, may move into summer dominant high rainfall (>500mm) region.
Serrated tussock	*Nassella trichotoma* (Nees.) Hack.ex Arechav.	Expected to retreat southwards and to high altitude because it is sensitive to temperature. As drought tolerant plant, it should become more invasive in an areas where temperature allows.
Prickly acacia	*Acacia nilotica*	Expected to move southwards and into arid areas

Figure 1a. Wheat field infestation with *Parthenium*: An emerging problem due to seed admixture.

Figure 1b. *Azolla* (earlier as weeds) cultivation and utilization in field crops.

Figure 1c. Monitoring of weed diversity pattern in fallow land.

Figure 1d. *Polygonum aviculare* (knotweed) infection in wheat field due to weed shifting (Coochbehar, West Bengal).

Figure 1e. Collection of soil sample for weeds seed bank.

Figure 1f. Reduced weed problem under zero tillage practice.

Figure 1g. Study on change in weed pattern under changing climate.

Figure 1h. Monitoring and weed management programme, Kalyani (Nadia, West Bengal).

$27^{0}13'$N) was one of the native places of different kind of *Swertia* species. Out of various species, *Swertia chirayita h*as long been used in the various treatments. The bitter infusion of the plant is used for skin disease, blood purification and as a bitter tonic for fever and indigestion. The presence of xanthones in the species is reported to remedy tuberculosis. Various species of Swertia is still treat as weeds because of little knowledge about their use. We did few survey programmes in North Eastern Himalaya during 2005 to 2014 and found number of plants which become quite beneficial for one community, and have no value for other people because of weedy in nature (Mukherjee, 2009a).

Biological diversity of weeds

Biological diversity is a term that may refer to diversity in a gene, species, community of species, or ecosystem. According to the Convention on Biological Diversity, biodiversity means "the variability amid living organisms from all source including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part" (CBD, 1992). Weeds have numerous interactions with other organisms and some of these interactions can have direct effects on the functioning of the agro-ecosystem. Such association create lot of biological diversity in our ecosystem. Few plant (may be weeds) are major food source for animals such as pollinators that preserve uncommon plant species, earthworms, granivorous and omnivorous arthropods such as carabid beetles, ants, pollinators, e.g., farmland birds and mammals. These plans can be conserved, based on their utility in nature (field condition), keeping in mind ecosystem balance feature. Weeds are the part of dynamic ecosystems, start off in ordinary environment and become obstacle to the crops, however this is the important source of pollination and home of number of beneficial insects. Weed biodiversity plays a key role in supporting food webs and ecosystem services in agro-ecosystems. One important service, that reduces weed abundance, is the predation of weed seeds by invertebrates and vertebrates. Weed biodiversity may be helpful to maintain seed predator occurrence (Kulkarni *et al.*, 2017; Schumacher *et al.*, 2020).

Impact of farming practices on weed biodiversity

Mechanized and improve farming practices become threat to not only our ecosystem but also very challenging for conservation of biodiversity pattern also. From a human perspective plant can provide sources of fuel, medicines, raw materials for many processes, protection, as well as aesthetic pleasure. Crop, animal, horticultural and forestry production systems are essential for food and non-food products. These are critical component of modern land use, that have evolved as agriculture and associated industries have developed. Plants are a key part of biological diversity as well. Threats to plants from non-target impacts of weed management within production systems may impact on biological diversity. Those impacts, mediated directly or indirectly through the elimination of plants or effects for example on reproductive potential, could influence ecology function by affecting soil processes, nutrient cycling and trophic interactions via fauna, flora, microflora and fungi. A balance is needed between the methods of production applied, the demand for products and the environmental impacts that occur. Changes in farming practices that have been recognized as causing declines in biodiversity include 1) concentration on one season crop either winter or rainy season crops with a consequent loss of other season crops, 2) increased farm specialisation with a decline in livestock and grass enterprises in arable areas and 3) change in farming date. Plant species diversity is negatively influenced by high soil fertility, herbicide application and spray drift into the margin, high disturbance levels, decreasing landscape connectivity and reducing habitat quality. Species diversity generally declines with increasing soil fertility. This is likely to be the indirect effect of fertility through competition rather than a direct effect. Fast-growing species outcompete the slower-growing ones for light and nutrients. Soil fertility can be reduced by maximising the off-take, e.g., in crop yield, or manipulation of stores and fluxes, e.g., nutrient cycling. Research has found that fertilisation increased vegetation productivity significantly and tillage decreased community biomass at the start of the growing season. Disturbance increases below-ground competition and fertilisation encourages above-ground competition. Productivity is suggested to affect species diversity. Colonisation rate of perennial forbs and grasses decreased and extinction increased with increasing productivity of the vegetation. Accumulated litter and lower light penetration in highly productive vegetation possibly inhibit germination and survival of seedlings, thus decreasing the colonisation rate. Competitive displacement in vegetation on fertile soils increases the extinction rate, thus resulting in a loss of species diversity. Just as all plants, weeds are a home and a source of food to a number of animals. Weeds matter for the biodiversity of all kinds of creatures (insects visiting flowering weeds or of birds eating their seeds). Therefore, we can say weeds has lots of beneficial effect in our agro-ecosystem. They do tender an assortment of remarkable profit to all of us, as well as to our food growers. For example, scientist establish that the bright blue cornflowers – which are weeds, too – specifically attract hoverflies. Hoverflies are true *friends*, as they pollinate plants and eat aphids, a feared crop pest. When hoverflies and other so-called natural enemies of pests (such as ladybugs) are attracted to the field by weeds, they devour aphids.

Weed shift

Shifting of various weed in crop field mainly owing due to different weed management practice, which do not control the total weed community or population in particular field. The management practice could be herbicide use or any other practice such as tillage, manure application, or harvest schedule that brings about a change in weed species composition (Mukherjee, 2018). Some species or biotypes are killed by (or susceptible to) the weed management practice, others are not affected by the management practice (tolerant or resistant), and still others do not encounter the management practice (dormant at application). Shifting of weed flora pattern under changing climatic situation become very challenging for food growers, scientist and researcher. For example, due to growing rice under alternating flooding regimes and residual soil moisture conditions prevalent in the Cauvery Delta region of Tamil Nadu, red sprangle top *(Leptochloa chinensis)* and European water clover *(Marsile'a qu'adrifolia*) became predominant in rice fields by replacing barnyard grass *(Echinochloa* sp.) (Yaduraju, 2012). In the eastern Indo-Gangetic Plains, adoption of zero tillage has resulted in an increase in population of globally-significant perennial weeds such as purple nutsedge (*Cyperus rotundus* L.) and Bermuda grass (*Cynodon dactylon*) (Malik and Kumar, 2014). Observation revealed that, effective weed control with various tillage option enhances crop yield significantly, with little effect on weed biotypes (Mukherjee, 2017), Such shifts are likely to occur in other production system as well suggesting that weed flora need to be monitored continuously in all cropping systems and agro-ecological regions in order to assess emerging weed problems and plan weed management strategies accordingly (Mandal and Mukherjee, 2018).

The weedy rice problem become quite significant under lowland rice ecosystem (Mukherjee, 2014). Weedy rice is broadly defined as plants from the genus *Oryza* that much resemble, mimic, infest and compete with rice. Pattern of weed distribution varies in different season of rice from lowland to upland situation (Mukheree, 2009). Weedy rice is reported as a serious pest of direct seeded rice systems (DSR). Weedy rice can spread rapidly, is highly competitive and can dramatically reduce rice yield and quality. The particular problem is that seeds of weedy rice species mature and shatter before rice, injecting large seed numbers into the soil seedbank. The shift to DSR accompanied by widespread, often exclusive, use of herbicides for weed control in rice can rapidly result in major problems with weedy *Oryza* species. Due to many morphological and physiological similarities between weedy rice and rice plants the control is a difficult and complex long-term endeavour. Research undertaken at Research farm and at farmers' fields in Haryana showed that there was a quick shift in weed flora with change of establishment method from puddle transplanted rice (PTR) to DSR (Yadav *et al*., 2011). Aerobic grass weeds such as *Leptochloa chinensis, Eragrostis sp., Dactyloctenium aegyptium* and *Eleusine indica* which were minor weeds in PTR became major weeds in DSR. Infestation of various sedges such as *Fimbristylis miliacea, Cyperus sp*. also increased under DSR. On the other hand, *Echinochloa crus-galli* still remains the dominant weed under puddle transplanted rice with little or no infestation of aerobic grass weed species. Weed infestation in DSR research trials was so high that in unweeded situations rice grain yield was reduced by more than 50%. In addition to the diverse weed flora, the prolonged weed emergence further added to the complexity of weed management in DSR. Within DSR, there was less and delayed weed emergence under moist sowing of DSR than dry sowing (irrigating the field after sowing). Stale seedbed technique proved effective in reducing weed infestation in DSR, along with controlling previous season's volunteer rice plants. Inclusion of green cover crops like mungbean, cowpea and *Sesbania* also helped in decreasing the weed infestation in the main DSR crop, along with their added advantage as green/ brown manure manure (Yadav *et al*., 2011).

Bruckner *et al.* (1997) surveyed weeds in maize area between 1 July and 31 September 1996, and the findings compared with those of surveys conducted in 1990. An increase in the average cover and frequency of occurrence of *Panicum miliaceum*, *Mercurialis annua* and *Ambrosia artemisiifolia* was observed. Many species not recorded in 1990 were registered (*Eragrostis minor*, *Amaranthus graecizans*, *Digitaria sanguinalis* and *Geranium pusillum*). Such changes in weed flora composition over time are referred to as weed shifts. A weed shift may be defined as 'the change in the symphony or relative frequencies of weeds in a weed population or community in reply to human-made or natural ecological change in a farming system'. Shifts in weeds are not new. Weed shifts have happened as long as humans have cultivated crops. Weedy and invasive species can easily adapt to changes in production practices in order to take advantage of the available niches. The behavior of a weed population rely on the nature of the environment experienced by individual plants. Increase in the size of a population is achieved through reproduction of the individuals that survive to maturity and by gains from immigration. Survival may occur by persistence in a dormant state (as seeds in the soil) or by escape from control as seedlings or plants (through chance or due to genotype, as in herbicide resistance). It is therefore, the reproductive contribution of these survivors that is important in the expansion of the population. Examples of weed shifts that have occurred in recent history include the following:

Community shift in response to herbicide use: With the use of clodinafop in wheat weed flora was mainly composed of *Poa annua*. Similarly in maize continuous use of pre-emergence atrazine give subsequent flushes of *Commelina banghalensis, Brachariar amosa* and *Ageratum conyzoides*. In the Corn Belt and winter wheat areas of the western United States, changes in weed communities were noted within 10 years of the introduction of 2,4-D for the control of broadleaf weeds. In corn, summer annual grass species increased as broadleaf species were controlled. In wheat, winter annual grass species replaced broadleaf species as the predominant troublesome species.

Community shift in response to tillage change: Changes from conventional to reduced tillage systems often cause weed community shifts that include increases in summer annual grasses and small-seeded summer annual broadleaves, winter annual, biennial, and perennial species, and decreases in large-seeded summer annual species.

Community shift due to new localized or long-distance introductions: Common lambs quarters, a weed believed to be native to Europe and Asia, is now found throughout much of the United States. In much of Pennsylvania, common lambsquarters has become predominant in the weed community. The shift occurred because the species grows aggressively, is difficult to control, and is a prolific seed producer. Long-distance dispersal has also resulted in the introduction of many noxious weeds to the United States, some of which have caused weed community shifts (including field bindweed in the western plains, leafy spurge in rangeland, and multiflora rose in pasture). Under Indian conditions, *Phalaris minor* in wheat and invasion of grasslands and pastures and other non-cropped areas with *Lantana* and *Parthenium* are typical examples.

Population biotype shifts in response to herbicide use (herbicide-resistant populations): In the mid-west, in many populations of common water hemp (pigweed species), biotypes differed in susceptibility to ALS-inhibiting herbicides. With recurrent spraying of ALS-inhibiting herbicides, populations shifted from susceptible to highly resistant biotypes. Other ALS-resistant pigweed species have also developed in several areas of the United States, including the northeast. Most recently, glyphosate resistant weeds such as horseweed (mares tail) and pigweed species are a problem in different regions of the U.S. as a direct result of glyphosate use in herbicide resistant crops.

Practices influence weed biodiversity pattern

All food webs are built on the primary trophic level of producers, which are plants. In agro-ecosystems weeds provide shelter, food, mating sites and oviposition. Consequently, reduction in unwanted plant species affect top level of trophic. Mainly invertebrate species intimately linked with specific weed species have gone or lost along with their possessions. Preservation of weed flora diversity, thus a means to the restoration of higher or top order taxa (invertebrates and vertebrates) in the food web.

Under this situation, weeds or any unwanted plant species not only supporting overall food webs and species range, but they also offer numerous bionetwork services such as pest control and pollination etc. They rely on the species and the diversity of the species performing the respective service and their functional interactions to work properly. This connection between biodiversity and bionetwork services in farming systems has been describe for cover crops and grasslands (Baraibar *et al*., 2018), but rarely for weed community (Blaix *et al*., 2018). Pest control (insect, weed etc.) is one of the most important aspect of our agricultural system. Amidst various pest measures, weeds reduced crop yield by 33 to 79 % per annum (Mukherjee, 2019). Distribution of weed flora in farming area or field depends on tillage, crop type, use of herbicide pattern, that choose a explicit set of weed species from the soil seed bank (Ryan *et al*., 2010; Schumacher *et al*., 2018). Therefore, management decisions of the farmer were reflected by the weed community composition and diversity and are often linked to a certain farming intensity.

Few measures such as in no till system of gave 5 to 40 % higher weed seed predation (Navntoft *et al*., 2016) and with more recurrent harrowing harmfully impact on the arthropod population (Navntoft *et al*., 2009) can furthermore affect the populations of seed predators. Herbicide use has been documented to cause a decrease in seed removal of 10-20% and abridged weed population by 15-47 % (Mukherjee, 2020) most presumably through removal of aboveground vegetation. WSP rates are therefore influenced by particular farming practices and their intensity. A diverse weed flora provides a wide spectrum of different seeds for seed predators. The food preferences of the predators can differ significantly at the species level (Wall and Nielsen, 2012). Therefore, an increased food resource diversity has most likely a positive effect on food web interactions (Harvey *et al*., 2008).

Weeds pattern in conservation agriculture

Effective soil tillage in farming practice, influence unwanted plants by uprooting, dismember, and bury them deep enough in soil to prevent further sprouting or emergence. Ploughing also moves weed seeds both horizontally and vertically, and changes the soil environment; thereby inhibiting or promoting weed seed germination and emergence. Reduction in tillage intensity and frequency, as practiced under conservation agriculture (CA), generally increases weed infestation (Singh *et al*., 2015). Our observation revealed that, in comparison with conventional tillage (CT), presence of weed seeds was more in the soil surface under zero tillage (ZT), which favours relatively higher weed germination. Use of different tillage option with various fertilizer level become quite economical in term of yield and check the weed population up to certain extent depend on soil edaphic factor (Mukherjee, 2019). Increased weed infestation was recorded in aerobic direct-seeded rice than with conventionally puddled transplanted rice (Singh *et al*., 2008). Similarly, Mishra *et al*. (2012) observed that over the course of time, a ZT–ZT sequence favoured relatively higher weed growth over a CT–CT sequence in a rice– wheat system. While weed growth in the initial year was not higher under the ZT–ZT sequence, in the third year of experimentation total weed dry weight was significantly higher under the ZT–ZT than CT–CT tillage sequence. Further, changes from conventional to conservation farming practices often lead toa weed flora shift in the crop field, which in turn dictate the requirements of new weed management technologies involving various approaches, viz. preventive measures, cultural practices (tillage, crop residues as mulches, intercropping, competitive crop cultivars, herbicide tolerant cultivars, planting dates, crop rotations etc.), and herbicides, is of paramount importance in diversified cropping systems. It may be noted that weed control in CA depends upon herbicides and agronomic practices. However, the recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in CA, and enabling to have uniform crop stands and yield levels similar to conventional tillage systems. In CA systems, the presence of residue on the soil surface may influence soil temperature and moisture regimes that affect weed seed germination and emergence patterns over the growing season. The composition of weed species and their relative time of emergence differ between CA systems and soil-inverting CT systems. There is mounting evidence that retention of preceding crop residues suppresses the development and germination of weeds in minimum tillage systems, thus enhancing system productivity. The composition of weed species and their relative time of emergence differ between CA systems and soil inverting CT systems. Brar and Walia (2007) reported that CT favoured the germination of grassy weeds in wheat compared with ZT in a rice-wheat system across different geographical locations of Punjab, while the reverse was true in respect to broad-leaved weeds. Some weed seeds require scarification and disturbance for germination and emergence, which maybe enhanced by the types of equipment used in soil inverting tillage systems than by conservation tillage equipment. The timing of weed emergence also seems to be species dependent. Bullied *et al.* (2003) found that species such as common lambs quarters (*Chenopodium album*), field penny cress (*Thlaspi arvense*), green foxtail (*Setari aviridis*), wild buckwheat (*Polygonum convolvulus*), and wild oat (*Avena fatua*) emerged earlier in a CA system than in a CT system. However, redroot pigweed (*Amaranthus retroflexus*) and wild mustard (*Sinapis arvensis*) emerged earlier in the CT system. Changes in weed flora make it necessary to study the composition of weed communities under different environmental and agricultural conditions. Certain weed species germinate and grow more profusely than others under a continuous ZT system. As a consequence, a weed shift occurs due to the change from a CT to a ZT system. For example, the infestation of awn less barnyard grass (Mishra and Singh, 2012), rice flat sedge (Ladha and Kumar, 2009), Indian Sorrel (Chhokar *et al*., 2007), nutsedge (Ladha and Kumar, 2009), field bindweed (Shrestha *et al.* 2003), crabgrass (Chauhanand Johnson 2009), Burclover (Mishra and Singh, 2012), goat weed (Chauhan and Johnson, 2009), crow foot grass (Chauhan and Johnson, 2009) has been found to increase; while others like little canary grass (Chhokar *et al*., 2009), wild oat and lambs quarters (Mishra and Singh, 2012), Bermuda grass, Italian ryegrass and yellow star thistle (Scursoni *et al*., 2014) showed decline under ZT compared with CT. Some weed species are not affected by tillage systems followed. For example, although emergence of awn less barnyard grass (*Echinochloa colona*) and rice flat sedge (*Cyperus iria*) was higher under continuous ZT than continuous CT or rotational tillage systems (ZT– CT and CT– ZT); no such tillage effect was noticed on pink node flower (*Caesulia axillaris*). Higher seedling emergence of awn less barnyard grass (*Echinochloa colona*) and rice flat sedge (*Cyperus iria*) under continuous ZT was attributed to their small seed size, which failed to germinate when buried deeply in CT (Mishra and Singh, 2012). A shift in weed populations towards small-seeded annuals is generally observed under conservation tillage systems. Contrary to this, in spite of small seed size, little canary grass has shown a remarkable reduction in their population under ZT compared to CTsystem in the Indo-Gangetic Plains. Weeds shifting towards perennials have also been observed in conservation tillage systems. Perennial weeds thrive in reduced or no-tillage due to non-uniform distribution pattern of root and herbicide were not effective to control them. Perennial monocots are considered a greater threat thanperennial dicots in the adoption of reduced tillage systems. Unlike annuals, many perennial weeds can reproduce from several structural organs other than seeds. For example, purple nutsedge (*Cyperus rotundus*), tiger grass (*Saccharum spontaneum*) and Johnson grass (*Sorghum halepense*) generally reproduce from underground plant storage structures, i.e., tubers or nuts and rhizomes. Conservation tillage may encourage these perennial reproductive structures by not burying them to depths that are unfavourable for emergence or by failing to uproot and kill them. Change in weed distribution pattern due to weed shifting and loss in crop yield because of more weed biomass production resulted in less adoption of conservation agriculture.

Climate change effect on weed flora

The multiple adverse impacts of global warming and climate change on food production involves many factors The global climate is changing along with measuring temperature and CO_2 level changes that are considered major drivers of climate change, there is also increasing attention being given to its impact on agricultural production systems (including weeds). Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Climate conditions exert a significant influence on the spread, inhabitants' dynamics, existence cycle duration, infestation pressure and the overall occurrence of the majority of agricultural pests (Mukheree, 2018a). Weeds are among the agricultural pest that can be influenced by climate change. It is expected that climate change will bring about a shift in the floral composition of several ecosystems at higher latitudes and altitudes, as changes in temperature and humidity will be reflected on flowering, fruiting and seed dormancy. Changes in atmospheric CO_2 levels, rainfall, temperature and other growing conditions will affect weed species 'distribution and their competitiveness within a weed population and within crop. Changing and increment of temperature is one main characteristics of climate change which may affect existing plants (weeds distribution) and allow some other plants (weeds) to replace native and will be expand in to new areas which is not existed before (Mukheree, 2014b). The direct impacts of climate change will be either on the biology of the biological control agent and/or on the ability of the host plant to resist, tolerate or compensate for the presence of the herbivore or plant pathogen. Rising temperature would be likely to amplify the rate of life cycles of both the biological control agents and the unwanted plants. Weeds have a greater genetic diversity than crops. As a result, if a resource such as water, light, nutrients or CO_2 changes within the milieu, it is more likely that weeds will show a better growth and reproductive reaction. Many weed species have the C4 photosynthetic pathway and so will show a lesser retort to atmospheric CO_2 relative to C3 crops. Till date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is improved (Ziska, 2010). Scientist observed significant increase in photosynthesis and decrease in stomata conductance in C3 weed (*Chenopodium album*) but no change in *Amaranthus retroflexus* (C4 weed) at elevated CO_2 level (Ziska *et al*., 1999; Ziska and Georg, 2004). Response of different plant under drought situation varies and few crop cultivar become more tolerant to other species. Under drought situation, few weeds produce alleleo-chemical that made weeds to flourish well and fight with crop (Patterson, 1995).

Upland and rainfed lowland rice with limited precipitation face severe competition with C4 weeds. Under imposed drought, (Patterson, 1986) found that the effects of water stress and significantly increased leaf area and total dry weight of the three C4 grasses: *Echinochloa crusgalli, Eleusine indica* and *Digitaria ciliaris*. Further, scientist also concluded that CO_2 enrichment can increase the growth of both C4 and C3 plants under water stress, but growth stimulation can be expected to be greater in C3 plants. Weeds of rangelands like cheat grass (*Bromus tectorum*) and yellow star thistle (*Centaurea solstitialis*) depend largely on available soil moisture for seed germination. Long-lasting or profound winters that deeply improve the soil moisture favour more production of seed in above mentioned two species (Patterson, 1995). Further these two species are also drought tolerant. However, their drought adaptive feature varies as per field situation by shorter lifespan in cheat grass and deeper root system for star thistle, compare to other native species.

Weeds monitoring and weed management strategies

Weeds are opportunistic '*colonising species*' or '*pioneers of secondary succession*' that are well adapted to grow in locations where disturbances, caused either by humans or by natural causes, have opened up space. Species can turn out to be weeds, as they are adjustable, aggressive, highly prolific, and are able to abide a broad array of ecological situation, including those in farms, or disturbed habitat. Recognition of new weeds phenotype in field condition and their main cause of dispersion (weed escapes) is vital for preventing shifts in weed populations or weed establishment. Significant advancement in improved weed management methods have allowed farmers to attain increases in crops productivity under well managed situation, without losing crop biodiversity. In spite of this, the weeds menace is increasing in cultivated and non-cultivated lands, as the weeds are dynamic. This may be attributed partly to weeds response to high-input and intensive cropping systems adoption with lesser adoption of traditional practices like intercropping, mulching and crop rotations; herbicide resistance development in weeds like *Phalaris minor*; changing climate and occurrence and predominance of more aggressive and adopted weed species; growing menace of: i) weedy rice or wild rice in many states, particularly where direct-seeding of rice is adopted; ii) *Orobanche* in mustard growing areas; iii) alien weeds (*Parthenium hysterophorus*, *Lantana camara*, *Ageratum conyzoides*, *Chromolaena odorata* and *Mikania micrantha*) invasion in many states of India. Hence, continuous weeds monitoring and weed management strategies and technologies development is needed to reduce the adverse effects weeds on farm productivity and maintain positive ecological balance (Mukherjee, 2019a).

Properly and timely weed control measure on regular basis through improve monitoring technique, is an important component of integrated weed management (IWM). Proper identification of different weed species during the seedling stage, based on its socioeconomic value is important. Seedling stage become more important because it is easier to control either via herbicide or via mechanical measures without affecting main crop. Perennial weeds are susceptible to control at early phase (i.e., bud stage) or during fall when the plants begin to go dormant. Chemical control measures at these stages can be translocated to the rhizomes or roots to enhanced kill the unwanted plant or weed. Weeds frequently grow up in patch so it can be managed through spot application of herbicide instead of whole field. A spot treatment can save money and time while getting better weed control and keep biological diversity as well. A handheld GPS unit is helpful to mark various patch of difficult weeds for spot treatment and succeeding monitoring. Keeping in mind weed biodiversity importance weed management strategy should focus on:

- Better understanding of weeds
- Monitoring of weed dynamics and its behaviour patterns
- Herbicide resistant weeds monitoring and prevention
- Climate resilient IWM strategy and technologies development.
- Herbicide residue management
- Invasive weeds management
- Adopting cautious approach on herbicide tolerant crops

Conclusion and recommendations

Sustainable strategies for managing weeds are crucial to meeting agriculture's latent to feed the world's population while conserve the ecosystems and biodiversity on which we depend. Under the threat of climate change, the core concern is the balance between adequate weed control, including the prevention of weed seed build-up, and the requirement for some plants to support biological diversity within crops. For some, clean crops and zero tolerance of weeds is the approach, with non-crop areas supporting biodiversity. A balance is essential amid the methods of production applied, the demand for products and the environmental impacts that occur. In relation to weed control, there are initiatives to apply herbicides only to the areas of fields where competitive weeds occur. This will require weed detection systems and/or accurate weed mapping and possibly real-time control of the application of different herbicide products.

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Chapter [4]

Protected areas in biodiversity conservation of India: An overview

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Abstract

Habitat loss due to human activities and weather extrade is synergistically posing critical threats to the worldwide biodiversity main to irreversible extinction of diverse species. In wake of recent extinction, numerous forests are declared as protected areas wherein no greater human activities are allowed. However, the scope of these protected regions got broadened from mere conservation to poverty comfort and sustainable improvement within the course of the beyond decades. Though those protected regions appear to be supportive of the biodiversity conservation, numerous disputes and gaps have emerged that want to be addressed for powerful conservation and sustainable control in those protected areas. Although governmental regulations have addressed variety of these contests, handiest constrained achievement has been finished up to now. Therefore, similarly research wants to judge the performance of protected areas for biodiversity conservation and devise the mechanisms for powerful sustainable control of these protected areas.

Keywords Biodiversity, Conservation, National parks, Protected areas, Wildlife

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Introduction

Protected regions are legally mounted sites controlled for conservation of biodiversity. Worldwide approximately 8,163 protected areas cowl over 750 million hectares of marine and terrestrial ecosystems, amounting to 1.5 % of Earth's surface. Protected regions are described geographical areas which might be controlled so as to make sure their long time conservation, presenting us with beneficial environment offerings and cultural values. They are critical to maintaining biodiversity and human livelihoods and additionally offer us with answers to trendy demanding situations inclusive of food and water security, human fitness and well-being, minimising disaster risk and weather change. Today, there are about 200,000 protected regions within side the world, which is 14.6% of the world's land and 2.8% of its oceans. India is the second maximum populous country, and consequently any plans trying at conservation have to don't forget socio-financial improvement because the mounting human stress threatens the biotic assets of the country. Furthermore, ours is predominantly an agriculture country, and hence, policy makers have to recognise that conservation and sustainable usage of biodiversity is the important thing to all developmental making plans projects.

Biodiversity conservation has to be directed to inventorization of organic sources in special components of the country which includes the island atmosphere. Conservation of biodiversity via a community of protected regions which includes National Parks, Wildlife Sanctuaries, Biosphere Reserves, Tiger Reserves, Marine Reserves, Gene Banks, Wetlands, Mangroves and Coral Reefs. Rehabilitation of rural poor/tribes displaced because of advent of protected regions. Conservation of micro-organisms which assist in reclamation of wastelands and revival of organic ability of land. Protection and sustainable use of genetic sources/germplasm via suitable legal guidelines and practices. Regular entry to organic sources of the country with the motive of securing equitable percentage in advantages out of using organic sources and related expertise regarding it. Control of over-exploitation by TRAFFIC, CITES and different agencies, and additionally through treaties/protocols//environmental safety legal guidelines at National/International level.

Protection of domesticated plant and animal species with the intention to preserve indigenous genetic diversity. Maintenance of corridors among special nature reserves for the feasible migration of species in reaction to climate, or another demanding thing. Support for protective conventional abilities and expertise for conservation. Multiplication and breeding of threatened species with present day strategies of tissue culture and biotechnology. Discouragement of monoculture creation. Restriction on creation of distinctive species without feasible investigations (Figure 1).

Types of biodiversity conservation

During the last twenty years, plans for biodiversity conservation have been developed by the WRI and the IUCN with support from World Bank and other institution. There are two approaches of biodiversity conservation namely,

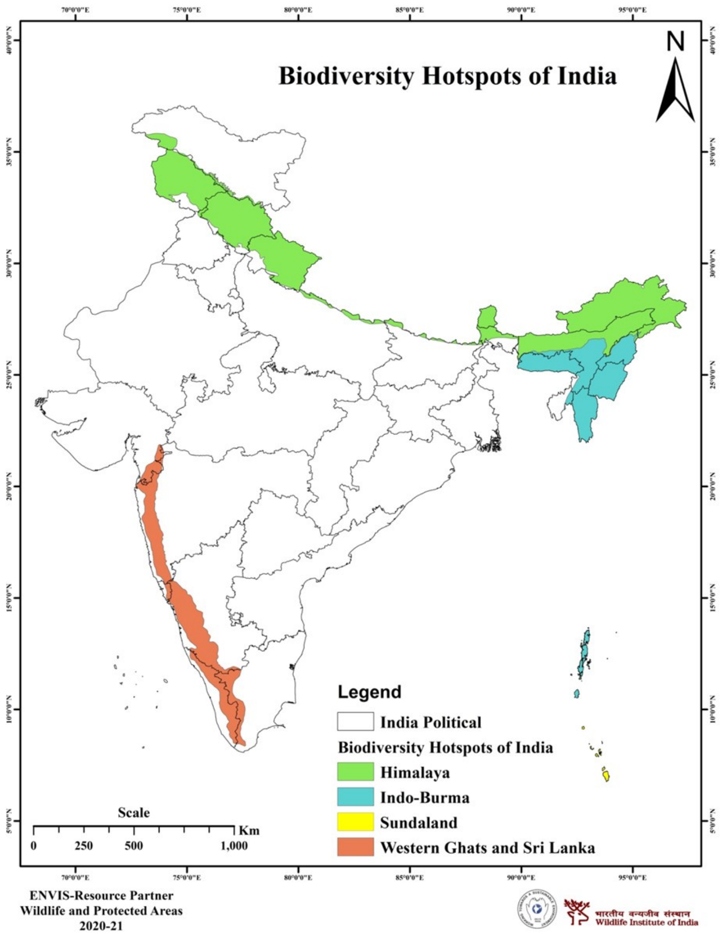

Figure 1. Map showing Biodiversity Hotspots of India (As on August, 2020; Source: WII, India).

1. *In situ* (on site) conservation - protect the specie in their natural habitat
2. *Ex situ* (off site) conservation - protect and preserve a species in place away from its natural habitat (Kumar *et al*., 2020).

Protected area contributions to conservation

No bird or mammal is understood to have been misplaced from India because the cheetah (*Acinonyx jubatus*) changed into extirpated with inside the mid-twentieth century (Divyabhanusinh, 1999). Protected areas have performed an essential position on this success (Karanth *et al*., 2010; Walston *et al*., 2016). For example, >85% of the world's one-horned rhinos (*Rhinoceros unicornis*) and >70% of the world's tigers stay in India, in large part a effect of the efficient functioning of India's Tiger Reserves (Jhala *et al*., 2015; Talukdar *et al.,* 2008). For birds, protected regions offer primary refuges for plenty species in low numbers. The 3 Gyps vulture species, after experiencing a 97% populace decline in overall because of veterinary use of the drug diclofenac, at the moment are in large part determined inner or close to National Parks (Prakash *et al*., 2019).

Types of protected areas

- National Parks
- Wildlife Sanctuaries
- Conservation Reserves
- Community Reserves
- Marine Protected Areas
- Tiger Reserves
- Biosphere Reserve

The National Wildlife Database Cell of Wildlife Institute of India (WII) has been growing a National Wildlife Information System (NWIS) at the Protected Areas of the country. India has 981 Protected Areas along with 104 National Parks, 566 Wildlife Sanctuaries, ninety seven Conservation Reserves and 214 Community Reserves protecting a complete of 1,71,921 km^2 of geographical region of the country that is about 5.03% (E-supplementary resource 1).

National Park: An area, whether within a sanctuary or not, can be notified by the state government to be constituted as a National Park, by reason of its ecological, faunal, floral, geomorphological, or zoological association or importance, needed for the purpose of protecting & propagating or developing wildlife therein or its environment. No human activity is permitted inside the national park except for the ones permitted by the Chief Wildlife Warden of the state. There are 104 existing national parks in India covering an area of 43,716 km^2, which is 1.33% of the geographical area of the country (National Wildlife Database, December, 2021) (E-supplementary resource 1).

Wildlife Sanctuary: Any area other than area comprised with any reserve forest or the territorial waters can be notified by the State Government to constitute as a sanctuary if such area is of adequate ecological, faunal, floral, geomorphological, natural or zoological significance, for the purpose of protecting, propagating or developing wildlife or its environment. Some restricted human activities are allowed inside the Sanctuary area. There are 566 existing wildlife sanctuaries in India covering an area of 1,22,420 km^2, which is 3.72 % of the geographical area of the country (National Wildlife Database, December, 2021) (E-supplementary resource 1).

Conservation Reserves: Conservation reserves and community reserves in India are terms denoting protected areas of India which typically act as buffer zones to or connectors and migration corridors between established national parks, wildlife sanctuaries and reserved and protected forests of India.

Such areas are designated as conservation areas if they are uninhabited and completely owned by the Government of India but used for subsistence by communities and community areas if parts of the lands are privately owned. These protected area categories were first introduced in the Wildlife (Protection) Amendment Act of 2002 − the amendment to the Wildlife Protection Act of 1972. These categories were added because of reduced protection in and around existing or proposed protected areas due to private ownership of land, and land use (Table 1).

Community Reserves: Conservation reserves and community reserves in India are terms denoting protected areas of India which typically act as buffer zones to or connectors and migration corridors between established national parks, wildlife sanctuaries and reserved and protected forests of India. Such areas are designated as conservation areas if they are uninhabited and completely owned by the Government of India but used for subsistence by communities and community areas if part of the lands is privately owned. These categories were added because of reduced protection in and around existing or proposed protected areas due to private ownership of land, and land use.

Marine Protected Areas: A marine protected area (MPA) is essentially a space in the ocean where human activities are more strictly regulated than the surrounding waters - similar to parks we have on land. These places are given special protections for natural or historic marine resources by local, state, territorial, native, regional, or national authorities.

Tiger Reserves: Project Tiger was launched by the Government of India in the year 1973 to save the endangered species of tiger in the country. Starting from nine reserves in 1973-2016 the number is grown up to fifty. A total area of 71027.10 km^2 is covered by these project tiger areas.

Biosphere Reserve: Biosphere Reserves are areas of terrestrial and coastal ecosystems which are internationally recognized within the framework of UNESCO's Man and Biosphere (MAB) Programme launched in 1971. These reserves are required to meet a minimal set of criteria and adhere to a minimal set of conditions before being admitted to the World Network of Biosphere Reserves designated by UNESCO for inclusion in the World Network of Biosphere Reserves. Biosphere reserves are helps to promote sustainable development based on local community efforts and sound science. The first biosphere reserve of the world was established in 1979, since then the network of biosphere reserves has increased to 631 in 119 countries across the world and 15 numbers in India (Figure 2).

Structure of Biosphere Reserve: The Biosphere Reserves are constituted on a core-buffer strategy (Figure 3).

- Core zone forming the sanctum sanctorum
- Buffer zone that concentrically surrounds the core zone

Core area: It is kept free of biotic disturbances and forestry operations, where collection of minor forest produce, grazing, human disturbances are not allowed.

Buffer zone: It is managed as a 'multiple use area' with twin objectives of providing habitat supplement to the spillover population of wild animals from the core conservation unit and to provide site specific eco-developmental inputs to surrounding villages for relieving the impact on the core. No relocation is visualized in the buffer area, and forestry operations, Non-Timber Forest Produce (NTFP) collection

Table 1. Protected areas of India from 2000 to 2020 (As on December, 2020).

Year	**No. of National Parks**	**Area Under National Parks (km²)**	**No. of Wild Life Sanctuaries**	**Area Under Wild Life Sanctuaries (km²)**	**No. of Community Reserves**	**Area Under Community Reserves (km²)**	**No. of Conservation Reserves**	**Area Under Conservation Reserves (km²)**	**No. of Protected Areas**	**Total Area under Protected Areas (km²)**
2000	89	37803.10	485	108862.50	-	-	-	-	574	146665.60
2006	96	38392.12	503	111229.48	1	0.31	4	42.87	604	149664.78
2007	98	38428.88	507	111529.04	5	21	7	94.82	617	150073.74
2008	99	39441.74	510	113123.35	5	21	45	1259.84	659	153845.93
2009	99	39441.74	512	113395.36	5	21	45	1259.84	661	154117.94
2010	102	40283.62	516	113842.87	5	21	47	1382.28	670	155529.77
2011	102	40283.62	518	113998.75	5	21	52	1801.29	677	156104.66
2012	103	40500.13	526	114933.44	5	21	59	2012.93	693	157467.50
2013	102	40500.13	532	117123.63	19	30.94	64	2232.61	717	159887.31
2014	103	40500.13	535	118290.66	43	58.22	64	2232.61	745	161081.62
2015	103	40500.13	541	118866.44	44	59.51	71	2548.82	759	161974.90
2016	103	40500.13	543	118917.71	45	59.66	72	2566.20	763	162043.70
2017	103	40500.13	544	118931.80	46	72.61	76	2587.95	769	162092.49
2018	104	40501.13	544	118931.80	46	72.61	77	2594.03	771	162099.47
2019	101	40,564.03	553	119,756.97	163	833.34	86	3,858.25	903	1,65,012.59
2020	104	43,716	566	1,22,420	214	1,302	97	4,483	981	1,71,921

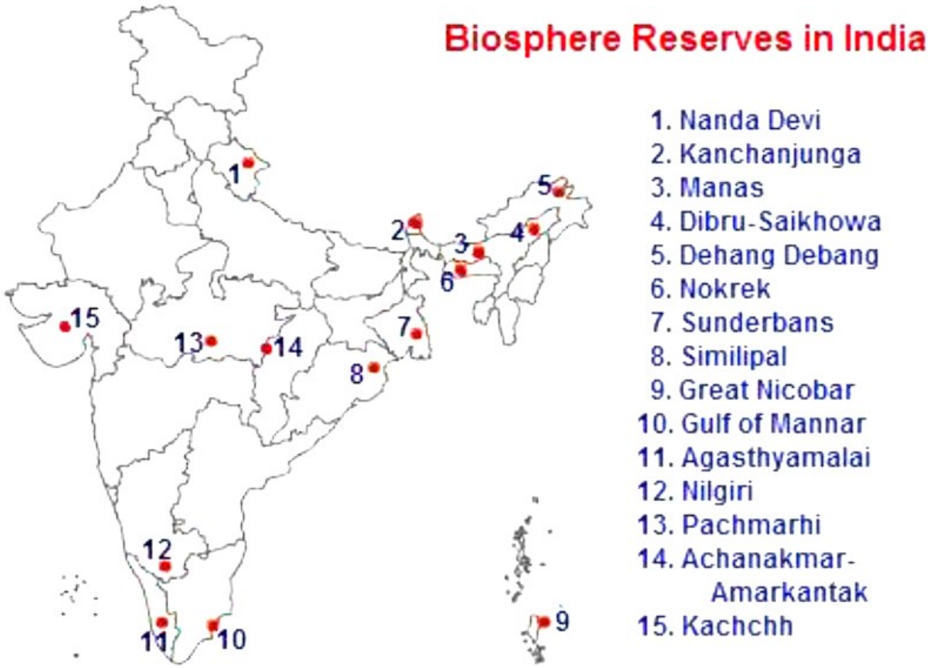

Figure 2. Biosphere Reserves setup in India.

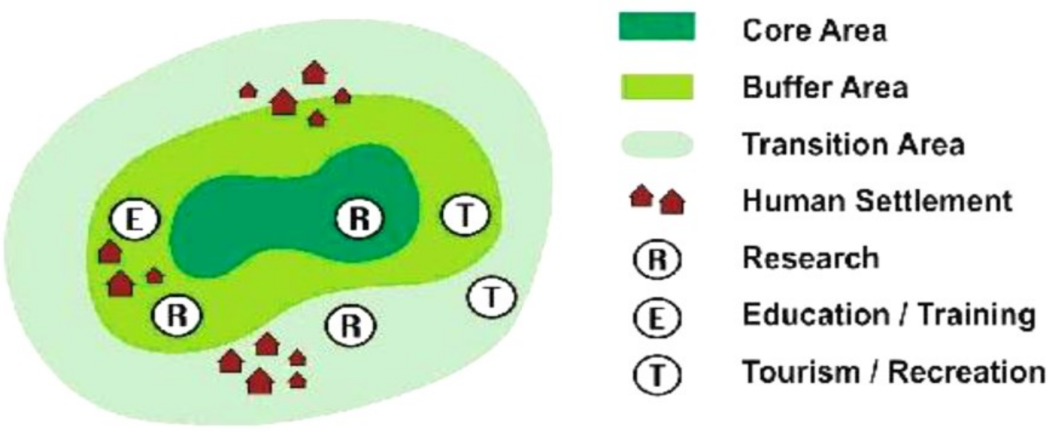

Figure 3. Structure of a model biosphere reserve.

and other rights and concessions to the indigenous communities are permitted in a regulated manner to complement the initiatives in the core unit (Kumar *et al*., 2020).

Threats to protected areas

Hunting: Hunting is another understudied threat. Hunting pressure clearly varies across regions and taxa, but is particularly intense in north east India. India's wildlife laws entirely prohibit hunting of wildlife in these forests, but enforcement is weak. Tribal communities have a strong tradition of hunting for meat, medicine, ritual customs, recreation, and increasingly for income (Aiyadurai *et al*., 2010). Beyond tigers, the primary targets are hornbills, ungulates, pheasants, bears, and primates (Datta *et al*., 2008a), although other groups such as squirrels and small carnivores are also hunted (Datta *et al*., 2008b; Dollo *et al*., 2010).

Fragmentation: India is losing forest area at the rate of 0.2% per year, and >90% of remaining forest fragments are less than 1 km^2 in size. Global assessments indicate that habitat fragmentation in India is extensive (Crooks *et al.,* 2017). Beyond forest loss, fragmentation prevents movement in arboreal animals, such as the western hoolock gibbon Hoolock hoolock (Vasudev and Fletcher Jr, 2015). Isolation of fragments has resulted in increased human-elephant conflicts (Baskaran *et al.,* 2013), reduced gene flow among populations of tigers (Natesh *et al*., 2017) and forest understory birds (Robin *et al*., 2015) and altered species composition in mixed foraging bird flocks (Sridhar and Sankar, 2008).

Climate change and invasive species: The richest locations for biodiversity in the east Himalaya should be relatively resistant to warming, given low anticipated climate change velocities (km/degree/year), facilitating tracking by flora and fauna. However, invasive plants are expected to be particularly adept at climate tracking, with presumed impacts on native flora (Mungi *et al*., 2018; Thapa *et al*., 2018). In the plains of India, high climate velocities in addition to the fragmented forested landscape may combine to accentuate threats from habitat loss and invasive species, and further intensify connectivity issues.

Protection measures: Establish and put in force measures for the rehabilitation and recovery of the ecological integrity of protected areas. Take measures to manipulate dangers related to invasive alien species in protected areas. Develop policies, enhance governance, and make sure enforcement of urgent measures that could halt the illegal exploitation of sources from protected areas, and improve global and nearby cooperation to do away with illegal change in such sources thinking of sustainable standard resource use of indigenous and neighbourhood communities

Conclusion

Protected areas were initially established to conserve biodiversity in the face of inevitable human-centred development. However, they have emerged as a critical tool for not only safeguarding species but also for poverty alleviation, improving human livelihoods, and overall development of a nation. The diverse ecosystems and ethnic groups of India do not allow a single conservation approach to be implemented successfully across the country. Therefore, a feasible approach based on primary field data should be promoted for the successful conservation of the species and ecosystems. Further, the success and failure of any protected areas should be judged on the basis of conservation of species and ecosystems rather than planning whether to restrict or allow local communities and other such factors.

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E-supplementary resource

Online version of this book chapter contains additional supplementary resource/data which can be accessed at: https://www.aesacademy.org/book/biological-diversity-current-status-and-conservation-policies.

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Chapter [5]

Climate change and its enormous impacts on global biodiversity

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Abstract

Biodiversity is being destroyed by human at a rate unprecedented in history. Since the industrial revolution, human activities have increasingly destroyed and degraded forests, grasslands, wetlands and other important ecosystems, threatening human well-being. About 75% of the earth's ice-free land surface has already been significantly altered, most of the oceans are polluted and more than 85% of the area of wetlands has been lost, the report showed. Average global temperature has increased by 0.74°C in last 100 years, rainfall patterns have changed and the frequency of events also increased. Change in climate has consequences on the biophysical environment such as changes seasons, glacial retreat, decrease in Arctic sea ice extent and a rise in sea level. These changes have impact on biodiversity, in term of phenology, distribution and populations, and ecosystem level in terms of distribution, composition and function. This chapter reviews the information about the importance of bio-diversity, threats to biodiversity, climate change and its impact on biodiversity and international approaches towards mitigating the effect of climate change.

Keywords Biodiversity, Climate change, Global temperature, Impacts, IPCC

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Introduction

India possesses a distinct identity, not only because of its geography, history and culture, but also because of the great diversity of its natural ecosystems. The panorama of Indian biological diversity is much wider, as it comes under the twelve mega biodiverse (Hot-spot) centers of the world. It contains a great wealth of biological diversity in its forests, its wetlands and in its marine areas which are distributed all over the country. This richness is shown in absolute numbers of species and the proportion they represent of the world total (Williams, 2008). Climate change has become the most crucial environmental concern of the decade. Much attention is rightly focused on reducing carbon emissions and greenhouse gases from industrial, energy and transport sector through reduction in fuel consumption and use of renewable/green energy. However, as countries are looking for mitigation and adaptation processes, protection of natural habitats is a key factor of climate change strategies. Strengthened support for protected areas and more sustainable resource management can contribute to strategies as well as for protection of the biological resources and ecosystem. Climate change is developing as one of the greatest threats to biodiversity, increasing pressures on genetic resources, species and populations. Biodiversity conservation and sustainable development are the possible ways to curtail the impact of climate change (CBD, 2009).

Convention on Biological Diversity (CBD)

The impacts of climate change on biodiversity are of major concern to the Convention on Biological Diversity (CBD). The Convention also recognizes that there are significant opportunities for mitigating climate change and adapting to it, while enhancing the conservation of biodiversity. In an effort to draw attention to the mounting threats and opportunities, the CBD is calling on the nations of the world to celebrate the International Day for Biological Diversity on 22 May 2007 under the theme "climate change and biodiversity" (Book *et al*., 2008).

Biodiversity

Biodiversity is a form of variation in life in different habitats of a certain ecological areas. It is a variation within and between species in particular habitats. It is the variation among living organisms from different sources including terrestrial, marine and desert ecosystems, and the ecological complexes of which they are a part. There are some subdivisions of the biodiversity like genetic diversity, species diversity and ecosystem diversity. Biodiversity is a remarkable association of the species of specific species and their associations.

Important values of the biodiversity

Source of food: It is a better sources of food to the living beings needed for generation and regulation of the life.

Source of medicine: It is a rich diversity of the plants in nature. Out of them many includes medicinal properties and are used as a sources of medicine to the peoples due to their effectiveness and low prize.

Ecological balance: In nature there is a specific and remarkable role of the each species. Each ones function is particular in nature. The roles of microorganisms are also significant with the role of plants and animals in varied directions.

Support to the species diversity: In nature each one species are interconnected in many ways of their life and are surrounded by the environment which affecting directly or indirectly to their life system.

Environmental conservation: It participating role in conservation of various components of the environment.

Control on soil erosion: Plants performing role in control on soil erosion in different zones.

Industrial values: It is a better sources of raw materials to the industry for formation of clothes, paper, Wax, Rubber and wool.

Recreational value and ecotourism: It provide recreation and also important for development of ecotourism.

Water resource protection: Biodiversity also maintain the quality and quantity of water in certain ecological areas. It manage against the effect of flood and drought

Pollution control: It is playing a significant role in pollution control in nature. By purifying the environmental components it is playing important role in pollution control.

Regulation of climates: Forests maintains the rainfall that supports the regulation of hydrological cycle in nature important for life of each species.

Educational values: It provides not only better facility to study on certain species and their life pattern but also support the scientific observation of the species in nature.

Biogeochemical cycles: Biodiversity regulates the biogeochemical cycles in particular ecosystem needed for better growth and development of the varied species.

Economic benefits: Biodiversity plays role in economic growth of the peoples as the nature with rich biodiversity is a better sources of valuable products such as food, medicine, fish and many more useful things to human beings.

Ethical values: Biodiversity focus on the human relationship with the other bio species in nature. So, due to ethical value the species are protected by the human beings.

Providing better chances to the species: The basic life requirements of the each species are presence of food, protection and better chances of reproduction.

Productive value: It is a better sources for productions of animal as well as plant products important for preparation of various beneficial products using it.

Existence values: It also support the life to live in nature and playing a great role in existence of the diversity of the species of the plants and animals both in certain ecological areas (Patel, 2015).

Composition of biodiversity

Ecological diversity: Biome- Bioregion- Landscapes- Ecosystems- Habitats- Population (Heywood, 1995).

Organismal diversity: Kingdom-Phyla-Families-Genera-Species- Sub species- Population.

Genetic diversity: Populations-Individuals-Chromosomes- Genes - Nucleotides.

Levels of biodiversity

- **Genetic diversity**: Genetic variability within a species
- **Species diversity:** Species variability within a community
- **Ecosystem diversity:** Organization of species in an area into distinctive plant and animal communities.

Genetic diversity: Every individual in a species differs widely from other individuals in its genetic makeup due to large number of combinations possible in the genes. This genetic variability is essential for healthy breeding population of a species.

Species diversity: Every natural and man-made ecosystem is made up of a variety of animal and plant species. Some ecosystems such as tropical rainforests are very rich in the number of species as compared to other ecosystems such as the desert ecosystem. At present the scientists have been able to identify 1.8 million species on the Earth.

Ecosystem diversity: There are a large variety of different ecosystems on the Earth. Distinctive ecosystems include natural landscapes like forests, grasslands, deserts, mountains and aquatic ecosystems like rivers, lakes and seas. Each of these also has man modified areas such as farmlands, grazing lands and urban lands. Any ecosystem that is over used or misused loses its productivity and gets degraded.

Biodiversity in India

Ministry of Environment, Forest and Climate Change reported (MoEFCC) that India is a mega diverse country contributing 7 to 8% of all recorded species, including 45000 plants species and 91000 animals species in the world, while India have only 2.4% of the world's land area. It is situated at the tri junction of the Afrotropical, Indo-Malayan and Palearctic realms, all of which support rich biodiversity. Being one of the 17 identified mega diverse countries; India has 10 biogeographic zones and is home to the mammalian species (8.58%), avian species (13.66%), fishes (11.72%), amphibians (4.66%), reptiles (7.91%), and plants (11.80%). Himalaya, Indo Burma, the Western Ghats-Sri Lanka and Sundaland are four out of 34 globally identified biodiversity hotspots are representing India. India's global ranking is 10^{th} in 633 birds (69 species), 5^{th} in reptiles (156 species) and seventh in amphibians (110 species). Total 811 cultivated plants and 902 of their wild relatives have been documented. Farm animals includes broad spectrum of of 34 cattle, 12 buffaloes, 21 goat, 39 sheep and 15 chicken as native breeds.

The area of Indian forests have covered over 692,027 km^2, cover 21.05% of the topographical area of the India, whereas forest cover has either remained static or has reduced in most of the developing countries. India has added around three million hectares of forest and tree cover over the last decade.

The total tree cover in India is estimated to be 9.08 million hectares, accounting for about 3% of the total topographical area of the India (MoEFCC, 2014).

Threats to biodiversity

- The key threats confronting India's biodiversity
- Habitat loss
- Fragmentation and degradation
- Unsustainable use and overexploitation
- Pollution
- Invasive alien species
- Climate change and desertification

The Living Planet Report is based on data from the Living Planet Index produced by the Zoological Society of London. The index is statistically created from journal studies, online databases and government reports for 20,000 populations of 4,200 species of mammal, bird, reptile, amphibian and fish, or approximately 6% of the world's vertebrate species (Figure 1). Indian biodiversity faces a variety of direct and indirect effects and challenges. National Forest Commission reported that the amount of these effects and challenges is very high, with as many as a third of all endemic species facing the threat of extinction (NFC, 2006). The demands of a growing human population for food, medicine, fiber, fodder, shelter and fuel, along with the need for economic development are putting and exponentially growing pressure on biodiversity and ecosystems across the country. Land use change, especially the expansion and intensification of agriculture, is creating pressure on habitats in some regions of the country through loss and fragmentation of forests, grasslands, scrublands, wetlands and other habitats. Agricultural escalation leading to loss of habitat heterogeneity, effects of agrochemicals on wild species, pollution and eutrophication due to agricultural runoff also threaten both species and the habitats (Soni and Farid Ansari, 2017).

Climate change

Climate refers to the general weather conditions of a place over many years. Climate change is a significant variation of average weather conditions i.e. conditions becoming warmer, wetter, or drier over several decades or more. It's that longer-term trend that differentiates climate change from natural weather variability. While "climate change" and "global warming" are often used interchangeably, global warming is the recent rise in the global average temperature near the earth's surface.

Effects on biodiversity: Climate change has been emphasized as serious threats to biodiversity which are likely to be adversative for biodiversity. Variation in precipitation and temperature are two important aspects of climate variability that are likely to have a direct and significant effect on India's biodiversity (Table 1 and Figures 1, 2 and 3).

Table 1. Climate change and potential impacts on biodiversity.

Climate change	Potential impacts on biodiversity
Increased ambient temperature	Species and population range shifts and/or changes in phenology leading to alteration or loss of biotic interactions
Changes in annual and seasonal precipitation	Changes in community composition
Increased frequency of extreme events	Mortality resulting from flooding after storms or drought events; damage or mortality resulting from deep freezes or heat waves
Changes to hydrologic regimes	Reduced stream flow affecting population persistence and community composition
Ocean acidification	Change in water chemistry affecting calcification rates of marine organisms
Sea level rise	Habitat loss and fragmentation affecting population persistence
Increases in ocean stratification	Reduced productivity of pelagic ecosystems
Changes in coastal upwelling	Changes in productivity of coastal ecosystems and fisheries

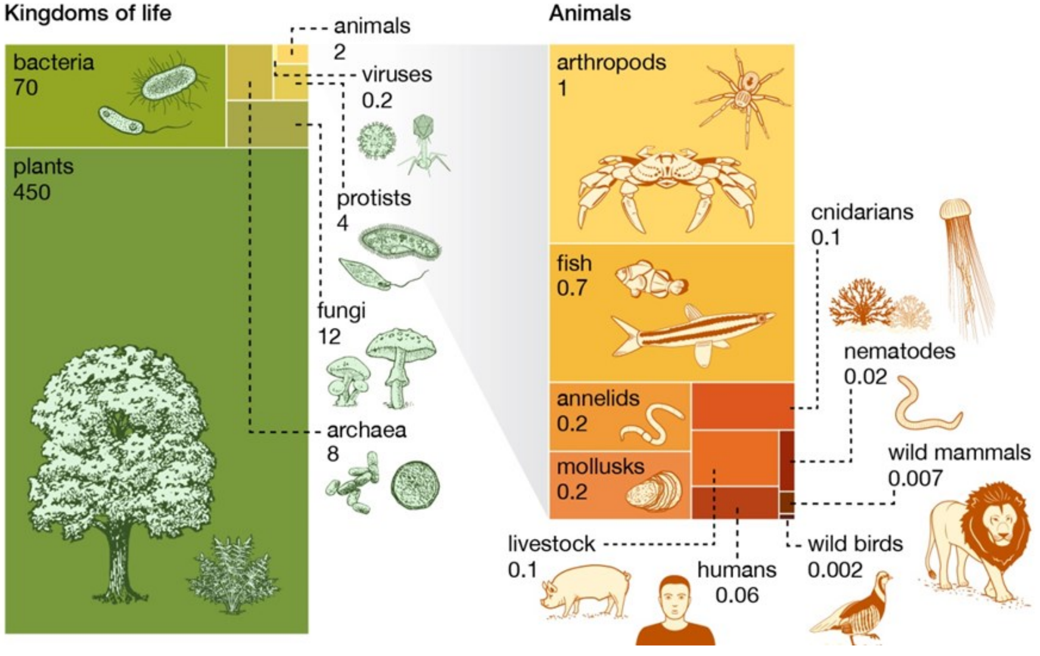

Figure 1. Relative biomass on Earth. The planet's biomass is classified by kingdom of life and other major groupings, and the size of each group's relative footprint is displayed using gigatons of carbon as the common measure (Source: https://www.britannica.com/science/living-things).

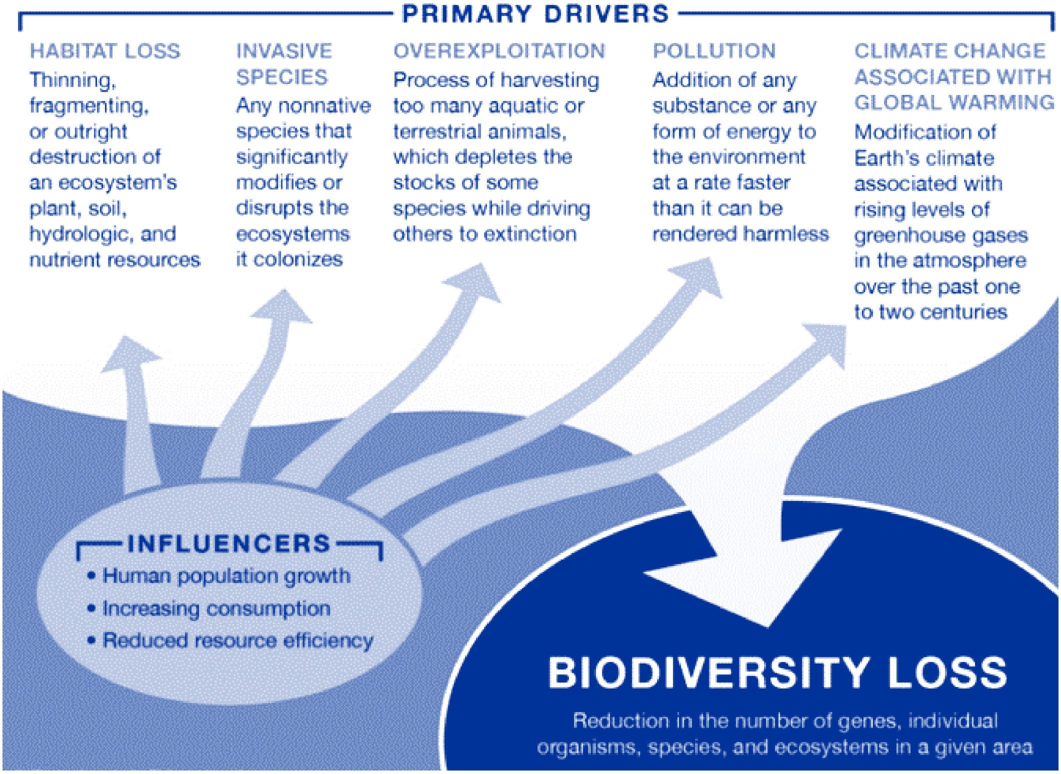

Figure 2. Threats to biodiversity (Living Planet report, 2020).

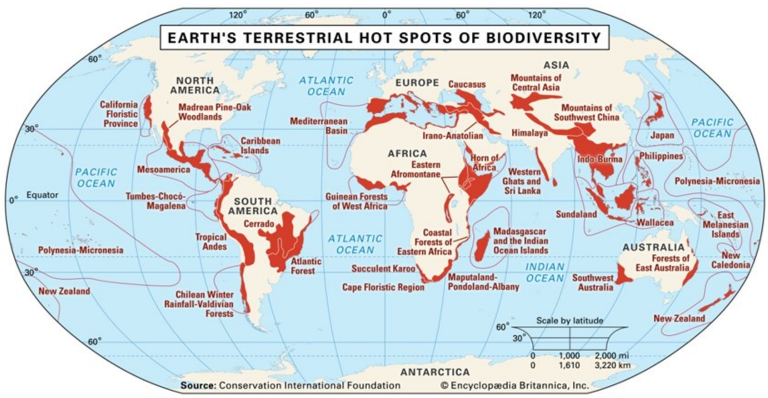

Figure 3. Terrestrial Hot Spots of Biodiversity
(Source: https://kids.britannica.com/students/assembly/view/107194)

Natural resources

Each 1^0C rise in temperature will lead to shifting the zone of occurrence of several specialist species by 160 meter vertically and 160 km horizontally. Although the specific impact of climate change on India's natural resources area wise is yet to be studied (Thuiller, 2007). Sukumar (1995) reported that endemic mammals like the Nilgiri Thar face an in-creased risk of extinction.

CO_2 levels and temperatures

Impact of climate change on biodiversity are expected to increase in magnitude and prevalence as CO_2 levels and temperatures continue to rise and in extreme conditions, i.e., heat and storms, increase in frequency and intensity (IPCC, 2007). IPCC has predicted that the resilience of many ecosystems will be threatened by an unique combination of climate change, associated disturbances such as drought, flooding, wildfire and other global change drivers such as land use change, pollution, fragmentation of natural systems, and overexploitation of resources (CBD, 2009).

Environmental changes

When it comes to land biodiversity, global warming is the biggest enemy of the polar regions. Fauna like polar bears, penguins, puffins, and other Arctic creatures will face a constant threat of losing their habitat through the diminishment of ice caps. As the ice melts, it increases the sea level, which will affect and perhaps destroy ecosystems on coastlines.

Wetlands and fresh water ecosystems

Climate change accelerate the damage to wetlands and fresh water ecosystems, such as lakes, marshes and rivers. Increasing temperature will cause water quality to deteriorate and have negative impacts on aquatic organisms, with the possibility of some species becoming extinct (Campbell, 2009).

Biodiversity vulnerability to climate change

The vulnerability of biodiversity to is dependent on the character, magnitude, rate of changes experienced by a species or system (exposure), the degree to which they are, or are likely to be, affected by or responsive to those changes (sensitivity), and the ability to accommodate with impacts with minimal disruption (Williams *et al*., 2008; Glick *et al*., 2011). The biodiversity is impacted by a range of anthropogenic stressors including land use change, non-native invasive species, exploitation, pollution and disease. In many cases, other stressors are currently or are expected to be the primary drivers of biodiversity loss (Flather *et al*., 1997, Wilcove *et al*., 1998). Overall, it is anticipated that the impacts of climate change will become increasingly prevalent and dominant in the coming decades and interact synergistically with existing stressors to affect biodiversity's vulnerability (Brook *et al*., 2008; Barnosky *et al*., 2011; Mantyka *et al*., 2012). Therefore an urgent priority is to carry out a comprehensive inventory and catalogue the status of biological diversity in the country before they are lost forever. This will enable the formulation of effective biodiversity management plans and also the ability to deter-mine if biodiversity changes are due to environmental degradation driven by other factors or due to climate change.

Impact of climate change on insect pest population

Increased temperatures will also increase the pest population, and water stressed plants at times may result in increased insect populations and pest outbreaks. This will affect the crop yield and availability of food grains and threaten food security. The climatic change impacts on pests populations may include: changes in diversity and abundance of insect pests, changes in geographical distribution of insect pests, increased overwintering insects, rapid population growth and generations, changes in synchrony between pests and their host plants, introduction of alternative host plants, changes in host plant resistance, changes in insect biotypes, changes in tritrophic interactions, impact on extinction of species, changes in activity and relative abundance of natural enemies, increased risk of invasive pest species, reduced efficacy of crop protection technologies and increased problems of insect transmitted diseases. These changes will have major implications for crop protection and food security, particularly in the developing countries, where the need to increase and sustain food production is most urgent. Long-term monitoring of population levels and insect behaviour, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. The impact of climate change will vary across regions, crops and species. A large number of models and protocols have been designed to measure the effects of climate change for different species and in different disciplines. There is a need for interdisciplinary cooperation to measure the effects of climate change on the environment and food security. It will be important to keep ahead of undesirable pest adaptations, and consider global warming and climate change for planning research and development efforts for integrated pest management (IPM) in the future (Sharma, 2010).

International approach on climate change

United Nations climate change conference: In November, 2015 United Nations Climate Change Conference, COP 21 was held in Paris, France. First time in the conference, it was concluded to meet their objective i.e. a global agreement on reduction of climate change in the Paris, which was adopted with acclamation by nearly all states.

Intergovernmental panel on climate change (IPCC): The intergovernmental panel on climate change is a dedicated body jointly established by the World Meteorological Organisation and the United Nations Environmental Programme (UNEP) has been assigned to prepare comprehensive document on scientific assessments of various aspects of climate change.

The United nations' framework convention on climate change (UNFCCC): The UNFCCC came in existence on 21 March 1994. The Rio Convention was adopted by UNFCCC at the Rio Earth Summit in 1992. The prime goal of the convention was to make stable the concentrations of greenhouse gas at a level that would prevent dangerous man made interference with the climate system.

The Kyoto protocol: A commitment by the parties for setting the internationally binding on emission reduction targets was made under the Kyoto Protocol which was linked to the United Nations Framework Convention on Climate Change and it was adopted in Kyoto, Japan, in December 1997 and come into force in February 2005.

The Bali road map: At 13th conference of the parties (3rd meeting) the Bali Road Map was adopted in December 2007 in Bali. This Map includes the Bali Action Plan, which plans the course for a new negotiating process designed to handle climate change.

National environment policy: An essential element of India's response to climate change has been out-lined in National Environment Policy (2006). These, interalia, include observance to principle of common but differentiated responsibility and respective capabilities of different countries, identification of key liabilities of India to climate change, in particular impacts on forests, coastal zones, agriculture, water resource and health, assessment of the need for adaptation to cli-mate change and inspiration to the industry to join in the CDM (Clean Development Mechanism) (Soni and Farid Ansari, 2017).

Solutions to biodiversity loss

Dealing with biodiversity loss is tied directly to the conservation challenges posed by the underlying drivers. Conservation biologists note that these problems could be solved using a mix of public policy and economic solutions assisted by continued monitoring and education. Governments, nongovernmental organizations, and the scientific community must work together to create incentives to conserve natural habitats and protect the species within them from unnecessary harvesting, while disincentivizing behaviour that contributes to habitat loss and degradation. Sustainable development (economic planning that seeks to foster growth while preserving environmental quality) must be considered when creating new farmland and human living spaces. Laws that prevent poaching and the indiscriminate trade in wildlife must be improved and enforced. Shipping materials at ports must be inspected for stowaway organisms.

Developing and implementing solutions for each of these causes of biodiversity loss will relieve the pressure on species and ecosystems in their own way, but conservation biologists agree that the most effective way to prevent continued biodiversity loss is to protect the remaining species from overhunting and overfishing and to keep their habitats and the ecosystems they rely on intact and secure from species invasions and land use conversion. Efforts that monitor the status of individual species, such as the Red List of Threatened Species from the International Union for Conservation of Nature and Natural Resources (IUCN) and the United States Endangered Species list remain critical tools that help decision makers prioritize conservation efforts. In addition, a number of areas rich in unique species that could serve as priorities for habitat protection have been identified. Such "hot spots" are regions of high endemism, meaning that the species found there are not found anywhere else on Earth. Ecological hot spots tend to occur in tropical environments where species richness and biodiversity are much higher than in ecosystems closer to the poles.

Concerted actions by the world's governments are critical in protecting biodiversity. Numerous national governments have conserved portions of their territories under the Convention on Biological Diversity (CBD). A list of 20 biodiversity goals, called the Aichi Biodiversity Targets, was unveiled at the CBD meeting held in Nagoya, Japan, in October 2010. The purpose of the list was to make issues of biodiversity mainstream in both economic markets and society at large and to increase biodiversity protection by 2020. Since 2010, 164 countries have developed plans to reach those targets. One of the more prominent targets on the list sought to protect 17 percent of terrestrial and inland waters or more and at least 10 percent of coastal and marine areas. By January 2019 some 7.5 percent of the world's oceans (which included 17.3 percent of the marine environment in national waters) had been protected by various national governments in addition to 14.9 percent of land areas.

Conclusion

Promoting the appropriate and effective coordination among biodiversity and climate change programs in India by incorporating the eco-friendly environmental policy, bringing the biodiversity and climate change into national plans and programs. Developing policy, guidelines for biodiversity, climate change and reduce the vulnerability of local communities to climate change impacts and enhance the flexibility of local communities to the impacts of climate change. Public participation is necessary to integrate ecosystem conservation and rural development, because it is necessary to know the needs for they depend on a particular ecosystem. Identify the key sectors of the country vulnerable to climate change, in particular impacts on water resources, agriculture, health, coastal areas and forests. Promote research to develop methodologies for tracing changes and evaluating impacts of climate change on glaciers, river flows and biodiversity.

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Chapter
[6]

Biodiversity conservation to mitigate the impact of climate change on agro-ecosystems

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Abstract

Biodiversity, or the diversity of living organisms on Earth, is an important indicator of the planet's health. Climate change mitigation requires preserving biodiversity levels and functional ecosystems; nevertheless, climate change is predicted to create major disturbances to the Earth's natural ecosystems, resulting in loss of biodiversity and a significant decrease in products and services offered to humanity. The present chapter deals with the impact of climate change that is severe to environmental issue that would jeopardize efforts to achieve long-term development and mitigation measures to reduce its impact on biodiversity changes. Furthermore, the impact of local and global species climate change has produced phenological changes in pollinators of flowering plants and insects, resulting in population mismatches, leading to plant and pollinator extinctions, with consequences for the structure of plant-pollinator networks. The loss of biodiversity and rising temperature can have an immediate impact on the water supply, food safety, soil nutrients, and human health. Conservation measure needs to be adopted, the land use pattern can be determined by remote sensing which is particularly valuable for detecting change due to the systematic coverage and lengthy time-series offered by satellite data.

Keywords Food, Human health, Remote sensing, Soil Nutrition, Species, Wildlife

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Introduction

The diversity of life on Earth at various levels, from genome to ecosystems, as well as the ecological, evolutionary, and social processes that keep life continuing, is referred to as biodiversity. Climate change forces a worldwide redistribution of life on Earth, whereas species geographical borders are dynamic and time-limited. For coastal, aquatic, and terrestrial species alike, the initial response to climate change is generally a shift in the site to retain favored circumstances. Climate change is expected to be one of the leading causes of global biodiversity loss in the future (Pawson *et al*., 2013). Various Ecosystems in biodiversity are especially sensitive to climate change, as compared to other life forms, they last for a long time and have a limited ability to react to sudden changes in the environment (Lindner *et al*. 2010). To understand how climate change impacts biodiversity, one must first comprehend the idea of biodiversity. Biodiversity refers to the overall diversity of all living entities on Earth, including genetic variety, species diversity, and the diversification of ecosystems (forests, coral reefs, and estuary) that they contribute to build and control. Biodiversity includes not only rare, vulnerable, or endangered species, as well as all living creatures, including bacteria, fungus, and invertebrates. Human intervention and activities in natural environments are affecting the biosphere all around the world. Human activities such as expanding agricultural production, urbanization, and resource usage and waste are all having significant impacts on the globe. This impact has led to certain consequences, like pollution, addressed effectively at local or national levels, while others such as ozone layer depletion, have been efficiently addressed through global cooperation. However, many of the effects caused by humans on the biosphere have yet to be completely addressed, and some of these have global implications at an unprecedented scale. As a result, biodiversity change encompasses more than just a decrease in species richness, such as the extinction of long-lived foundation species and their replacement by small, weedy organisms. Henceforth, Hillebrand *et al*. (2017) have described that biodiversity not only encompasses richness, or the number of species, but also qualities of identity, dominance, and rarities. Changes in climate patterns have had a significant negative influence on various ecosystems. The loss of biodiversity, the extinction of millions of species is a very real result of excessive utilization of natural resources. Climate change, caused by greenhouse gas emissions, can affect the composition of the atmosphere and the living conditions on the Earth's surface for humans and all other species (Thomas and Warner, 2019). Human modification of Earth's ecosystems has affected biodiversity in many parts of the world, including marine, terrestrial, and freshwater ecosystems, and more changes are anticipated as a result of rapid global change (Hillebrand, 2017). Such reductions in biodiversity have resulted in what is usually referred to as a "biodiversity crisis," with cautions that present rates of extinction are unusually high (Pimm *et al*., 2014).

Biodiversity is the life foundation system of the world where people depend on air, water, and food. The medications produced from wild species save countless lives and alleviate pain for an example of Aspirin, taxol, quinine, and Penicillin. Furthermore, wetlands screen out water toxins, while vegetation absorbs carbon, contributing to the reduction of global warming. Organic stuff, which fertilizes the soil, decays bacteria and fungus. The abundance of natural species and the human standard of living are associated with environmental wellness. The link between diversity and long-term viability appears to be becoming stronger. As a consequence, biodiversity conservation is required because humans and other living creatures rely on it. This chapter examines the influence of climate change on biodiversity, as well as its components and mitigation strategies, to understand the loss of diversity.

Types of biodiversity

The biological resources (genes, species, creatures, ecosystems) and ecological processes are a part and our examples of biodiversity. As a result, biodiversity is examined on three levels:

- Genetic diversity
- Species diversity
- Ecosystem diversity

Genetic diversity: The study of genetic diversity is used to define individuals or societies in comparison to others. It determines the degree of genetic variation in a population, which is a major source of biodiversity. Genes are the basic building blocks of biodiversity, serving as the building resources for the growth of plants, animals, communities, and ecosystems, which are a source of the huge variety that we are seeking to maintain, enjoy and utilize. Genetic variety in shape distinguishes individuals, populations, subspecies, species, and eventually kingdoms of life on Earth. Individual genetic diversity shows the presence of several alleles in the gene, resulting in a wide range of genotypes among species (Mukhopadhyay and Bhattacharjee, 2016). Genetic diversity is essential for survival and adaptation, as it allows for the continuation and advancement of adaptive processes that are essential for evolutionary success and, to some extent, human existence. Time, space, and fitness can all be used to measure survival and adaptation. Adaptation, genetic stability, and variability are all fitness factors. Extinction can occur as a result of biotic or abiotic pressures, such as competition, predation, parasitism, and disease, or isolation and habitat alteration as a consequence of natural calamities, slow geological and climatic change, or human activity (Rao and Hodgkin, 2002).

Species diversity: Species diversity, of living organisms, is one of the three layers of biological diversity, along with genetic diversity within species, species diversity, and ecological or community diversity. Biodiversity is however confounded with species diversity in many environmental assessments and the number of species in a given area is assessed (species richness). While the species is frequently thought of as the most fundamental unit in ecology, measuring the number of species to evaluate diversity raises several difficulties (Kempton, 2002). Trees offer basic needs and habitat for other species, specie variety, and stand structure are critical for forest biodiversity (Reilly and Spies, 2015). Furthermore, an understanding of forest diversity and stand structure is crucial for climate change control since manipulating them can result in the formation of forests that result in less emission (Sevegnani, 2016; Jenkins *et al.*, 2017).

Ecosystem diversity: On Earth, there are many separate ecosystems, each with its complement of diverse interconnected species based on habitat characteristics. Biodiversity is however confounded with species diversity in many environmental assessments and the number of species in a given area is assessed are examples of distinct ecosystems. Farmland and grazing pastures are examples of man-made environments in each region. The words 'eco' and 'system' refer to an area of the planet and to coordinating bodies. Live creatures of a habitat and their surroundings work as a single entity together. An ecosystem is a sort of an ecological unit which engage a natural interaction of life forms and the environment. The biotic community, which includes plants, animals, and other living organisms, is referred to as life. The biotope spanning the physical region of life is referred to as the environment (Balasubramanian, 2017).

Climate change and biodiversity

The term "climate" refers to the average weather conditions at a given location on the planet. Climate is usually described in terms of projected temperature, rainfall, and wind conditions based on past data. A change in the average climate or climate variability that lasts for a long time is referred to as "climate change". The climate of the Earth has always fluctuated due to changes in the Earth's orbit, the sun's energy output, volcanic activity, the geographic distribution of the Earth's landmasses, and other internal and external events. This form of long-term climate change is referred to as "natural climate change" by scientists. The Earth has endured frequent cold periods in the past as a result of natural climate change when glaciers covered vast portions of the Earth's surface. Warmer times on Earth have also occurred, with sea levels far higher than usual levels. According to the United Nations Framework Convention On Climate Change (UNFCCC, 2007), climate change will have profound impacts on the ecosystem, as well as the socioeconomic and related sectors of water resources, agricultural production, public health, terrestrial ecosystems, and biodiversity, and coastal zones. The fundamental cause of global warming is the rise in temperature caused by the entrapment of greenhouse gases. Carbon dioxide, methane, nitrous oxides, and chlorine and bromine-containing chemicals are among them. The accumulation of these gases in the atmosphere alters the atmosphere's radiative equilibrium. Greenhouse gases absorb some of the Earth's outgoing radiation and re-radiate it back towards the surface, which causes an overall impact to warm the Earth's surface and the lower atmosphere. Changes in rainfall patterns are predicted to cause drought conditions and flooding. Glacier melt can result in flooding and soil erosion. Rising temperatures may force agricultural growth seasons to alter, posing a threat to food security.

Impacts of climate change on biodiversity

Global data increase over the last two decades has indicated that the last half century's climate change has been a leading driver in creating considerable changes in biodiversity in numerous locations and habitat types (Shen and Ma, 2014). Climate change directly impacts biodiversity by changing basic habitat elements such as temperature and rainfall, and it triggers climatic risks such as drought, flooding, cooling, thunder, and temperature rise. These changes act as natural drivers of biodiversity dynamics, potentially amplifying secondary effects. Climate change has the potential to lower population biological variation as a result of directional selection and accelerated migration, which could have an influence on ecological processes and resilience (Bellard *et al*., 2012). Climate change has produced phenological changes in angiosperms and insect carriers, resulting in population mismatches, leading in plant and pollinator extinctions, with ramifications for the structure and composition networks (Kiers *et al*., 2010). Climate change may produce significant changes in native plants, putting biome integrity at risk at higher biodiversity levels. The multiple components of climate change are projected to be the major causes of biodiversity loss at all levels, alongside anthropogenic stressors. The loss of biodiversity as a result of climate change has altered the pattern and dynamics of energy and material circulation, either directly or indirectly (Zong and Wang, 2017). This has also resulted in the adaptation of the conversion of biological resources into useful commodities and services, specifically, the transformation of pastures and forests to croplands (Lambin and Meyfroidt, 2011). The generation of biological source of food, power and textiles and forests transformation for agriculture can have a direct effect on greenhouse gas emissions (Burnham and Ma, 2015). According to Thuiller (2007), each 10°C increase in temperature shifts the zone of occurrence of several specialist species by 160 meters vertically and 160 kilometres horizontally. Although the precise impact of climate change on India's natural resources has yet to be determined at scientific level. It has been revealed that greenhouse gas emissions are endangering biodiversity all across the world. Intergovernmental Panel on Climatic Change IPCC (2007) predicted in 2007 that by the end of the twenty-first century, global surface temperatures might rise by 1.8 to 40 degrees Celsius, and found that an increase of 1.5 to 2.50 degrees Celsius would risk the extinction of 20 to 30 percent of the world's plant and animal species. The climate has a significant impact on people's lives and livelihoods in socio-economic development. The climate has warmed by 0.890 degrees Celsius (0.69 to 1.080 degrees Celsius) between 1901 and 2012, owing primarily to anthropogenic activity (IPCC, 2013). Climate change and extreme weather events like hurricanes will have an impact on coastal development, water supply, energy, agriculture, and health. Walther (2010) described climate change as a cause of abiotic environments to shift, affecting biological systems and processes. The rate, amount, and nature of climate change, as well as ecological sensitivity and adaptation capability to environmental change, all influence biological responses. It's also been noted that a combination of these elements has an impact on biodiversity at all levels. Figure 1 shows the detailed impact of climate change on various components of biodiversity.

Impacts on species

Biodiversity planning is difficult in a changing environment since species population, might be declined or even vanish at some locations, flourish in others, and extend into new regions beyond their current ranges (Bellard *et al*., 2012). Over the past 200 years, world rates of extinction have rapidly climbed to considerably higher than in the last few years (Ceballos *et al*., 2015). Global concern has been expressed about these changes that may harm protected area networks, which are one of the most

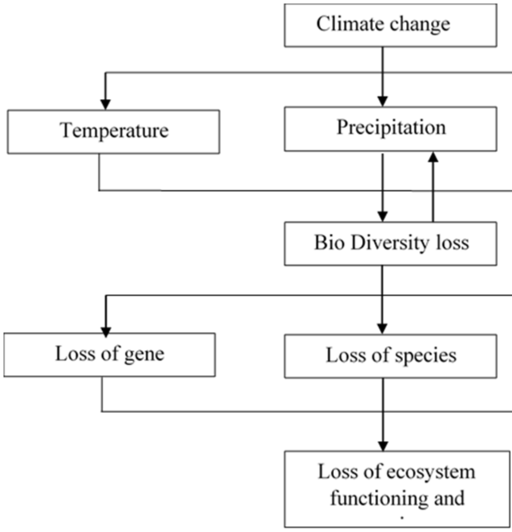

Figure 1. Link between climate change and its impacts on biodiversity and ecosystem services, and the impact of biodiversity loss on climate change (Sintayehu, 2018).

important instruments for reducing biodiversity loss. There are also projected climate change to have an influence on terrestrial biodiversity, including declines in the range and abundance of species (Warren *et al*., 2013). Protected areas, on the other end, must conserve populations large enough to have a low risk of extinction at the species level (McCarthy *et al*., 2011). While climate plays a key role in organizing large-scale diversity, the association between species-specific responses to patterns is well understood. Many ecological studies at macro scale have concentrated on pattern in local site diversity (alpha diversity), which is generally quantified in terms of species richness. For example, it is well known that species richness declines with increasing latitude and grows as the temperature rises (Davey *et al*., 2013). Beyond alpha diversity, species composition discrepancies between sites (beta diversity) and regional species pool diversity (gamma diversity) also play essential roles in regulating community richness and composition at different scales. These scales depend on the prediction of net changes in diversity. An increase in local richness may not lead to regional gains. Ward and Masters (2006) studied that 40% of the main insect pest species in North America are introduced species although comprises only 2% of total biodiversity of the insects. Likewise, roughly 30% of all insect and mite pests are introduced in Britain, while more notably, 62% are non-native of 29 major insect forest pests. Johnston *et al*. (2013) conducted a study to focus on two key bird assemblages of international importance; seabird breeding and wintering waters. The apparent strength of the network of protected areas does not ensure that every species is safeguarded from climate change repercussions. According to studies, by 2080, 41% of breeding seabirds and 53% of wintering waterbirds in the UK may suffer population declines of more than 25% due to climate change. Negative consequences in protected area populations, however, may be less negative than influences in the surrounding landscape. The impact of climate change on the population size of the species assembly across the national protected areas network, hence continuing the protection of huge numbers of breeding seabirds and wintering water-birds existing in the UK would be feasible over the next 70 years. Although certain species and assemblages are not protected from an inherent consequences of climate change and the assembly structure at each site may vary, these sites will continue to be locations where some fragile populations are conserved. Species with many characteristics could be classified as susceptible to climate change and risk in the future. From the 252 essential protected vertebrate species at the county level in China, the percentage lost (PSL) was 27.2% during about 50 years. Average mammalian PSL (47.74%) was higher than the amphibian and reptile ones and higher than the birds (28.8%) (He *et al*., 2018). The biodiversity of the species, their genes, and habitats include diversity, abundance, and identity (IPBES, 2019). In green environments, the function of genuine biodiversity is still very understood. Biodiversity covers the diversity i.e. (animal species, plants, fungus, and microbes) of species, but it also includes genes and diverse ecosystems within those species. Biodiversity declines, however, threaten the quality of life of all people, wealthy and poor, at an unprecedented rate. Environments provide supplies of food, fuel, fresh water, medicines, and other material, regulating the local and global climate, air quality, pollination processes, pests, and vector-borne diseases, provide habitat for biological diversity, and preserve genetic variation.

Impacts on human health

According to World Health Organization (WHO, 2015) definition Health "is a complete condition of physical and mental well-being, not only the absence of sickness or illness." Health status has substantial social, economic, behavioural, environmental. However, a wider view of health, includes other species, ecosystems, and fundamental unit of the ecological foundations. In reaction to irresponsible biodiversity management, the COVID-19 pandemic exposes public health risks around the globe (IPBES, 2020). In the formation of global and regional policy development, the importance of the underlying connections between biodiversity and the health of human is more and more recognized (Khaine *et al*., 2017). Global temperature rises and ozone layer depletion as a result of climate change have resulted in pain and skin disorders, which have a long-term influence on human health. Climate change has an immediate influence on human health, economy, water supply, and food security (Michelle *et al*., 2012; Adelodun *et al*., 2021a, b). At multiple geographic and temporal levels, the relationships between biodiversity and health are evident. On a global scale, ecosystems and biodiversity play a critical role in establishing the state of the Earth System, controlling material and energy fluxes, and responding to sudden and gradual changes. The human microbiota, symbiotic microbial communities present in our intestines, skin, breathing systems, can contribute to our nutrition, assist control our immune system, and avoid illnesses. Land-use change, habitat loss, pollution, invasive species, and climate change are direct drivers of biodiversity loss. Many of these drivers directly affect human health and its biodiversity implications. The continuing decline in biodiversity, including ecosystem loss or degradation, reduces the capacity of biodiversity and ecosys-

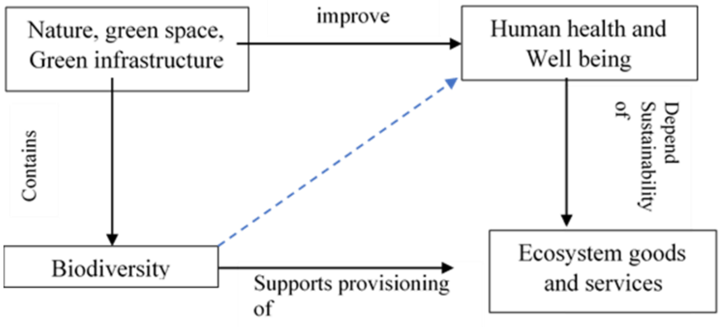

Figure 2. Linkages between nature, biodiversity, ecosystem services, and human health and well-being (Aerts *et al.*, 2018).

tems to offer fundamental services of sustainable existence, often leading to negative health and well-being effects. The degradation of the ecosystem can cause loss of biodiversity and risks of infection. Figure 2 represents the biodiversity, human health and ecosystem services. A wide variety of species are dependent upon the ecosystems, including food production systems, such as primary producers and herbivores, carnivores, and decomposers. Ecosystem services include food, clean air, freshwater, medicines, religious and traditional values, climate change regulations, the regulation of pests and diseases, and the decrease of disaster risk. The conservation and appropriate use of biodiversity can be beneficial to human health by conserving ecosystem services and alternative for the future. Because human health is inextricably related to the temperature ranges in which societies have been accustomed, deviations from ideal temperatures will influence morbidity and death (Gasparini *et al.*, 2015). One of the aspects of health hazards is temperature extremes. Heatwaves have already surpassed any other extreme weather-related occurrence in Europe in terms of cumulative death rates (European Environment Agency, 2017).

Biodiversity can have an impact on one's health and well-being by preventing or lowering illness. Among the most compelling examples of the importance of biodiversity to human health is medicinal medications obtained from natural sources. Natural products and genetic resources are found in biodiverse habitats, which are used in both traditional and modern medicine (van Wyk and Wink, 2017). For the majority of the human population, medicinal plants are the principal source of natural product medications (Romanelli *et al.*, 2015). Ekor (2014) according to study, found that 70–80 percent of the world's population is thought to rely on traditional medicine for their primary health care. Natural products account for 75% of all antibacterial, antiviral, and antiparasitic medications licensed in the United States (Newman and Cragg, 2012). Changing impacts on biodiversity have resulted in the availability of clean water for human consumption (World Health Organization, 2019). Biodiversity is critical to the provision and regulation of water quantity and quality. Much of the world's fresh water is supplied via river networks downstream from mountains, and forests play a significant role in flow management (Zhang *et al.*, 2017). Biodiversity is essential to the ecosystem's health because it supports ecosystem activities such as providing, regulating, and purifying freshwater.

Biodiversity, food production, supply chain and soil nutrition

Soil nutrition and biodiversity

Soil biodiversity's functional features are quickly evolving, partly as a result of the growing acknowledgment because of its importance in ecological processes and partly because of the benefits of excellent soils to public health and well-being. Rational soil use techniques must allow for economically and environmentally sustainable yields, which can only be achieved if soil health is maintained or restored. Cardoso *et al*. (2012) described soil health as the ability of soil, within ecological and land-use limitations, to work as a vital living system to sustain ecological integrity, enhance air and water quality, and maintain plant, animal, and human health. Soils and soil biodiversity, like most of the resources people rely on, are threatened by land degradation, climate change, pollution, urbanization, and overuse and exploitation (Montanarella *et al*., 2015). Soil biodiversity is important for biological soil water consumption, but many organisms also help with physical and chemical interactions between water and soil matrix. Soils and soil biodiversity like the majority of the resources on which people rely, are under threat from land degradation, climate change, pollution, urbanization, and overuse and exploitation. Nutrient transit across trophic levels is essential in both natural and agricultural ecosystems, and is predominantly mediated by soil fauna and microorganisms.. In a climax forest, up to 95% of nitrogen recirculates in an almost closed soil-plant-microorganisms circuit (Chen *et al*., 2003). The soil fauna and microbial population are important in any ecosystem because they influence soil organic matter decomposition, nutrient cycling, and soil chemical and physical properties, all of which have direct implications for soil fertility and sustainability. Soil biota, unlike most chemical and physical qualities, is very dynamic and is swiftly modified by soil usage and management, as well as any other disturbance. That is why edaphic organisms are useful markers of soil health, particularly when the indication corresponds to biological processes in the soil. Soil biodiversity is increasingly recognized as critical to the supply of ecological services for human well-being. Soil biota plays the role in:

- Formation of the soil, breakdown of organic matter, and nutrient cycling
- The control or eradication of the plant, pests and diseases;
- The synthesis of plant growth hormones;
- The supply of water can be regulated by adjusting soil structure, as well as water infiltration and storage.
- Flood and erosion control by soil structure change and water infiltration

Furthermore, soil biota affects climate by storing carbon and producing and consuming greenhouse gases (Bissett *et al*., 2013). Soil biodiversity is widely known for its function in regulating greenhouse gas emissions and soil carbon storage (Jackson *et al*., 2017). Climate, plant diversity, and soil biodiversity all interact to affect the balance of carbon in soils (Schimel *et al*., 2012). Soil organisms also help with litter breakdown and greenhouse gas emissions. Soil fauna enhances the surface area of litter by shredding leaves, which boosts microbial decomposition rates (Moore *et al*., 2004). In moderate and wet tropical regions, soil fauna generally increases litter decomposition rates, although this is not always the case in cold, dry regions (Frouz *et al*., 2015).

Recent research suggests that global climate changes impact the soil biota and modulate some ecological services, indicating that global change is one of the largest dangers to soil biodiversity (Garcia *et al*., 2015). In addition, rate of change of the environment, and the species sensitivity all influences the amount of global changes which affects soil biodiversity and functioning of ecosystem. The potential for a disconnect between above ground and belowground communities, changes in plant-soil feedbacks, negative effects of soil biodiversity loss on the resistance and resilience of ecosystem functioning to perturbation, and decreased ability of ecosystems to adapt to environmental change are just a few of the key concerns about global change impacts. These impacts have led to soil health chemical properties are that are linked to the ability to deliver nutrients to plants and/or to retain chemical components or chemicals that are damaging the environment and plant growth. The key chemical features employed in soil health assessment include pH, cation exchange capacity (CEC), organic matter, and nutrient levels, especially when considering the soil capability for supporting high yield crops (Kelly *et al*., 2009). Soil organic carbon has an impact on critical functional activities in the soil, such as nutrient storage, particularly nitrogen storage, water holding capacity, and aggregate stability (Silva and Sá-Mendonça, 2007). Microbial activity is also influenced by soil organic carbon. As a result, especially in tropical climates, this is an important component of soil fertility that interacts with chemical, physical, and biological soil qualities and must be considered in soil health evaluation. Nitrogen is the most important nutrient for the plants, and it can be found in various of chemical formation in soil (Cantarella, 2007), resulting in highly dynamic behaviour. Nitrogen in soil has mostly been assessed as mineral nitrogen, particularly nitrate, organic nitrogen, or potentially mineralizable nitrogen, as stored in organic materials in the soil. Microbial respiration is reduced in the long run by changes in vegetation, such as deforestation which lead to depletion of surface or rhizosphere organic carbon inputs into the soil (Bissett *et al*., 2013).

After such a disturbance, soil with a high microbial diversity has a better chance of maintaining biological processes. Resilience is a term that refers to a biological buffering system that protects an environment against disruptions. Individual biochemical properties have a considerable degree of fluctuation in response to climate, season, geographic location, and paedogenetic factors, which is the fundamental drawback of employing them as indicators of soil quality. Changes in land use have an impact on soil carbon storage, resulting in quantitative and qualitative changes in soil organic matter, as well as physical and chemical qualities that directly affect soil microorganisms, such as humidity, porosity, and density.

In contrast to climate change precipitation is one of the most important limitations on soil biota in many ecosystems, as well as one of the most important elements influencing microbial activity, owing to its impact on soil moisture content. Reduced precipitation has a detrimental influence on fungal biomass, collembolans, and enchytraeids, according to meta-analysis, with no discernible impact on other taxa

(Blankinship *et al*., 2011). Pereira *et al*., (2013) Reduced precipitation alters microbial community composition, implying that the ecosystem functioning may be harmed even if overall microbial biomass remains unchanged. Changes in precipitation volume, frequency, or seasonality are expected to have profound effects belowground, especially in dryland ecosystems where water is already scarce.

Agriculture and biodiversity

Biodiversity is critical for preserving natural ecosystem services that support global food, fiber, fuel, and fodder production. It's also one of the planet's most important regulators, allowing it to adapt to changing environmental conditions. Food and agricultural biodiversity (BFA) is a subset of biodiversity that aids in the production of food. It includes domesticated plants (crops), animals (livestock), aquaculture systems (fish farms), and forestry (timber), as well as other necessities such as cotton for textiles, biofuel components, and medicinal plants. BFA is just as reliant on the biodiversity as it is on food production and security. The global move to more intense agricultural and aquatic food production systems, on the other hand, is disrupting the environments where BFA thrives. As the world's population continues to grow, more land will need to be dedicated to agricultural production to satisfy the projected increase in food demand. This has the potential to increase the conversion of previously uncultivated land or to expand agricultural activities on land already exploited for food production. Agricultural biodiversity provides humans with food, raw materials for items such as cotton and wool for clothes, wood for shelter and fuel, herbs and roots for remedies, and biofuel materials. Agricultural biodiversity also provides ecosystem services such as soil and water conservation, soil fertility maintenance, biota conservation, and plant pollination, all of which are critical for food production and human survival. Stiles (2017) studied farmland habitat, also known as the agroecosystem, which is possibly the most important environment in the UK in terms of wildlife and biodiversity, as it accounts for about 75 percent of the country's land use. This environment has recently been linked to biodiversity loss and a decrease in the presence of wildlife as a result of post-war agricultural intensification.

Land use and intensity, of management are significant elements in the agro-biodiversity, ecosystems since both restrict food and wildlife availability. Management measures, like fertilizer, uses, grassland intensity, and grassland, moving frequencies have been demonstrated in a process called biotic homogenization to cause biodiversity loss. Crop production and livestock is an important driver of biodiversity loss which accounts for 50% of the total living area (excluding ice-covered land, etc.). This has caused habitat fragmentation, its condition deterioration, and its connectedness (the extent to which species or other environmental resources, such as nutrients, can move between similar habitat patches). In temperate zones, there are croplands even in many protected areas (Vijay and Armsworth, 2021). Climate change leads to a very high land, degradation rate, which leads to increased desertification and nutrient soils. The problem of land degradation is growing every day and is a huge worldwide problem. That has caused changes in soil processes that affect important soils are adversely affected properties like structure, organic content, capability for water retention, fertility, and pH. Changes in soil properties are largely due to changes in the variety and organization of living creature populations in soils. The occurrence of Water and wind erosion is predicted to grow because of increased seasonal precipitation differences with increased precipitation intensity and warmer temperatures leading to more drying out. Furthermore, significant changes in the soil's organic carbon content will vary with soil type and agricultural management. It has the dependence on the balance between inputs of carbon and losses of carbon occurring. Higher crop productivity and so more carbon inputs but also greater soil respiration rates will be present in warmer conditions, in which water is not a limiting issue. This makes it difficult to anticipate the net effect on soil carbon.

Impacts on agriculture-ecosystem

The major consequences of climate change across the agricultural ecosystem

Forestry: Warmer temperatures and extended seasons will promote growth in cooler, upland places, whereas in drier summer areas circumstances, will inhibit growth, particularly in the South and East, and could lead to drought, stress and fatality, especially among young trees (Marselle and Matthews, 2016).

Horticulture: Warmer temperatures are favourable to many vegetable crops generally, although new kinds may be needed to preserve production from winter chilling kinds. Lower precipitation can lead to drought stress in tree crops.

Livestock: The quantity and quality of food will have an impact on livestock productivity. Some livestock diseases may be more common (Morison and Matthews, 2016).

Soil: Warmer temperatures and less precipitation can lead to a loss of soil carbon, especially in peatland soils. Soil structure and fertility can be affected.

Groundwater: Reduced aquifer recharge and increased agricultural demand for water may limit groundwater supply for irrigation.

Grassland: Warmer temperatures and longer growing seasons are expected to boost grassland output, while changes in seasonal timing and rainfall amount will have an impact.

Land use: Temperature and rainfall variations will alter the classification of land suitability in some locations, potentially opening up chances for the cultivation of new crops, such as bioenergy crops.

River flooding: River flooding is predicted to become more frequent in the future, damaging crop and pasture productivity on neighbouring land.

Uplands: Warmer and drier circumstances will enhance production in colder, wetter highland locations, however more intense rainfall in some regions may result in increased soil erosion. The variety and quality of ecosystem services provided by upland areas may be influenced in both good and negative ways (Brown *et al*., 2010).

Arable land: Warmer temperatures suggest that crop growing seasons will begin earlier, that crops may have lesser yields due to maturation occurring sooner. Increasing the frequency of summer droughts will reduce yields in some locations, but higher winter rainfall may result in more waterlogging, increased compaction, and decreased land trafficability (Morison and Matthews, 2016).

Efforts for restoring agricultural biodiversity

Efforts are being undertaken for germplasm build-up, management, and evaluation of targeted underused crop species through 21 *National Bureau of Plant Genetic Resources* **(**NBPGR) centers located in diverse agro-climatic zones across India. The program's goals are mentioned below.

- To discover new plant sources for food and feed as well as industrial applications
- To acquire a large collection of germplasm as well as to characterize, conserve, and improve them.
- These crops are suitable for a variety of farming scenarios.
- To develop a suitable set of agronomic procedures for their commercial cultivation.
- To distribute information about possible species to increase their popularity.
- The Global Plan of Action for Plant Genetic Resources Conservation includes 20 actions. The majority of activities have received adequate attention in India. Over time, priorities have been refined (Richa *et al*., 2015).

Conservation measures

Biodiversity is vital for ecosystem function and services on which humans rely and is intimately linked to the economic, social, and environmental domains of sustainability, climate change has had an impact on biodiversity loss. It will be necessary to implement specific conservation measures in order to avoid biodiversity loss. Biodiversity conservation is concerned with the preservation of life on Earth in all of its forms, as well as the functioning and health of natural ecosystems. This includes protection, maintenance, long-term usage, rehabilitation, and promotion of biological diversity components. Where conservation refers to the responsible use of resources, which includes both protection and exploitation, and preservation refers to the act of preserving something without altering or modifying it. Another complex component of biodiversity conservation is sustainable development. This refers to the development that meets the current generation's demands without jeopardizing future generations' ability to meet their own. It simply means intergenerational equity also sustainable development ensures biodiversity conservation when there is a balance between the environment, development, and society. This is only possible if policies, conventions, and environmental institutions are properly enforced and implemented (Rawat and Agrawal, 2015).

Identifying the risks of changing land use patterns

Remote sensing, which is becoming increasingly precise and widespread, allows for exact evaluations of the major driver of extinction: habitat loss. Enhanced remote sensing is particularly important since tropical moist forests are home to roughly two-thirds of all terrestrial species, and a subset of them – biodiversity hotspots – are home to the vast majority of vulnerable species. RS is particularly valuable for detecting change due to the systematic coverage and lengthy-time series offered by satellite data. RS data and derivatives are critical inputs to models that forecast future states and patterns, allowing for early detection of change and quick intervention. Rates of change, rather than absolute changes, may be more important, making the frequency of repeats in a time series, as well as data continuity, significant.

The use of remote sensing to construct maps of terrestrial ecosystems is frequent. These maps are often based on a map that delineates specific vegetation types or land uses. The problem is that remote sensing must be combined with fast increasing data on species distributions in order to identify future fronts of species extinction, and adaption of these conservation measures helps to minimize climate change and global warming impacts. Conservation applications necessitate a connection that is fast enough for law policies, conservation groups, and others to respond. RS is critical for identifying and monitoring dynamic trends that influence ecosystems, species, and ecosystem services, with genome effects being a new area of study. Global area maps for terrestrial vertebrates are available, based on informal species distribution records and expert analysis (Ocampo and Pimm, 2014). Linking species habitat preferences with the qualities that satellites measure is required for remotely assessing land-use changes for species that live entirely or partially in different habitats. Species ranges are determined from data on species localities. Locality data might be linked directly to remote sensing, which would be a computationally difficult process but would eliminate intermediate steps. Remote sensing also offers information about the area's freshwater system, including flood mapping based on satellite measurements of the water body, retention time, and hydro-period. The estimations of chlorophyll level in water surface, sediment, and coloured dissolved organic matter concentrations, as well as estimates the water depth and clarity using optical RS, can be used to evaluate the trophic status of the water column. More can be done to increase the greater biodiversity conservation community's availability and use of RS. The use of RS is essential for monitoring land, marine, and aquatic life. Since more and different types of sensors are available, and as cooperation with the greater community improves, RS may play an increasingly vital role, providing global, periodic data that can improve our understanding of change and how society responds to it. (Walters and Scholes, 2017).

Protecting the wildlife sites

The distribution of biodiversity over the land and sea is significantly non-uniform. Because of geology, climate, topography, and human activity, some areas are more abundant and diverse in terms of species, abundance and diversity than others. Many species rely on the conservation and management of such ecosystems. Priorities are to be accorded to wildlife refuges as areas of ecological biodiversity conservation and protection, with no human intrusion. The nature wildlife sanctuary has been proven to be a location of the highest moral responsibility, where people willingly limit their rights and freedoms for the protection of the rights and freedoms of wildlife and other living creatures, with the best of intentions. National parks are nature preservation, ecological, educational, and scientific institutions, with natural complexes and artifacts of unique ecological, historical, and aesthetic value inside their territories (water areas). They're made to be used in environmental, educational, scientific, and cultural settings, as well as for controlled tourism. This is a critical component of conservation strategy, delivered through an evidence-based framework that identifies the most important regions. Offers legal protection, influences activity within their bounds, and seeks restoration to restore the damage that happens within them. These locations are critical components of the strategy to ensure that biodiversity can adapt to environmental changes, notably climate change (Gorbunov *et al*., 2019).

Priority species and habitats

Climate change is another additional concern to species, and its current and future effects are likely to worsen existing stressors (Hof *et al*., 2011). Due to the limitation, it is critical to assess which species are most vulnerable to climate change, whether current management locations are still suitable for target species, where future conservation areas must be targeted, and whether species will seek help migrating between current and future management areas. Priority habitats and species cannot be managed in solitude. The Ecosystem approach emphasizes the preservation of ecosystem structure and function to preserve ecosystem services. Ecosystems must be considered as a whole, and how many of the component's functions are dependent on one another, especially as these interactions respond to climatic and other environmental changes, following this thinking and the Millennium Ecosystem Assessment method. As a result, action will be taken to reduce the fragmentation of critical habitats and constraints on biodiversity in the larger environment in which species travel. Some of the new goals, such as increasing the patch sizes of grassy habitats and building landscape-scale complexes for wetlands, reflect these broader, landscape-scale initiatives Morison (Ruddock *et al*., 2007).

Conclusion

Biodiversity is a cornerstone of basic life not an optional addition in human matters. The conservation of biodiversity adapted to changing climate conditions is essential not just for species and habitats to adapt to change, but also for climate change mitigation. Halting biodiversity loss is a huge challenge, particularly in light of climate change, which will exacerbate many of the adverse drivers. The most important environmental worry of the decade is climate change. Carbon reduction requires a great deal of awareness and greenhouse gas emissions from energy, and its impact on water resources, human health, species, and agricultural practices. The influence of climate change on biodiversity and various components of nature are affected. Since, biodiversity refers to the diversity of all kinds of life, from genes to ecosystems. Changes in the fundamentals of biodiversity will have an impact on changes in biodiversity and its natural habitat on a broad scale. Furthermore, climate change has had a substantial impact on the flora, fauna, and species habitat, as well as on human health. These effects have had a significant impact on the natural environment of plants, animals, soil nutrients, and all other components. By storing carbon and creating and consuming greenhouse gases, soil biota has an impact on climate. Chemical qualities of soil quality are related to the ability of the soil to provide micronutrients and/or to retain active compounds or chemicals that are harmful to the environment and plant growth as a result of the impacts. Soil nutrient imbalances have harmed agricultural and crop output to meet global food demand. Certain technology and socio-economic measures to maintain biodiversity must be adopted to reduce the impact of climate change on biodiversity loss and their side effects on the environment. Changes in land patterns in a place over time might aid in monitoring changes in forest cover or vegetation in that area. As a result, conservation measures could be implemented to protect the area's forest species and animal species. Remote sensing technology is being used to create maps of natural ecosystems, which are typically based on a map that distinguishes different vegetation cover or land uses. The method of combining remote sensing with rapidly increasing data on species distributions in order to predict future fronts of species extinction and adapting conservation techniques to help mitigate the effects of climate change. Soil nutrients and endangered species can be protected in the area. Climate change has an impact on a variety of soil processes, notably those related to soil fertility. By monitoring the land change cover in the area, degradation of soil could be detected and the productivity of the soil can be maintained by taking measures to meet the global demand for crops and food. These measures help to mitigate climate change and reduce global warming.

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Chapter
[7]

Impact and assessment of climate change on biological diversity

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Abstract

Global climate change has both direct and indirect effects on the biological and physical contexts of biodiversity. Climate change's consequences include increased temperature and precipitation, high salinity, and intense climate conditions such as hurricanes, cyclones, and droughts, all of which have a significant negative impact on habitats and on the structure and functioning of the environment and ecosystems. Investigating the impact of climate change on biodiversity is difficult because changes occur steadily over time and the consequences are interactive with other environmental problems. In the previous two decades, there has been an increase in the number of endangered species, including plants, fish, amphibians, molluscs, birds, mammals, insects, and reptiles, among many other species. This chapter's major goal is to focus on biodiversity and the impact of global warming and climate change on terrestrial and aquatic ecosystems, as well as on the agriculture and human existence. Furthermore, numerous tools and methods for analysing the effects of climate change using diverse techniques, as well as potential mitigation measures for conserving biodiversity from climate change's consequences, have been discussed.

Keywords Biodiversity, Climate change, Ecological models, Mitigation, Range shift

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Introduction

According to the International Union for Conservation of Nature (IUCN), biodiversity is "the heterogeneity of life forms from all types of habitats and ecological complexes" (IUCN, 2010). There are between 5 to 30 million distinct species on Earth; the majority are microbes, with just approximately 1.75 million accurately recognised (IUCN, 2000). The interactions of all the elements that comprise the world's total biodiversity, considered as a whole, create the foundation upon which human civilization has evolved. Biodiversity loss is one of the most critical environmental issues, given how much it contributes to the world economy and human health (Martens and Rotmans, 2005). There has been a steady decline in species richness since 1970, according to the Living Planet Index. By 2020, it is anticipated that species populations would decline by 67 percent. In the previous two decades, there has been an increase in the number of endangered species, including plants, fish, amphibians, molluscs, birds, mammals, insects, and reptiles, among many other species. A ten-year period between 2006 and 2015 saw a loss of biodiversity in reptiles, molluscs, and fish, with average losses of 12.5% and 8.5%, respectively. World Wildlife Fund (WWF) (2016) attributes the decline in biodiversity to a variety of factors including habitat destruction and degradation, resource exploitation, unsustainable agriculture, fishing, climate change, and ecosystem pollution. Climate change will become one of the world's primary causes of biodiversity loss in the future, and there are compelling reasons to believe that climate change will result in the extinction of a number of taxonomic specie as well (Sala *et al*., 2000). The IPCC's 4th Assessment Report (AR4) affirmed that climate change is having a significant impact on many aspects of biodiversity. These implications will also have an impact on the ecosystem, the genetic diversity of animals, and ecological relationships. These effects have far-reaching implications for the natural world's long-term existence as well as the numerous benefits and resources that people derive from it.

Climate change, as one of the most important factors influencing organism growth and species densities, has the ability to affect the structure of plant and soil ecosystems, as well as their interactions. A steady increase in the average temperature of the Earth's atmosphere and seas is referred to as climate change. Climate change is one of the most significant factors influencing disaster risk, according to the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013). According to the Intergovernmental Panel on Climate Change (IPCC), global warming will continue to climb by 5.8°C by 2100, compared to 1.4°C in 1990 (IPCC, 2007).As a result of climate change, there may be a range of environmental and biological consequences (Lama and Devkota, 2009). The fast-growing trend toward warming has already had obvious and typically negative consequences on important resources, such as soil, living organisms, and water, during the previous few decades (Danovaro *et al*., 2004). Climate change, together with biodiversity loss, is a major issue on the environmental, social, cultural, and political fronts (Rosales, 2008). Further temperature rises of up to 3°C, according to the IPCC, will almost likely produce substantial changes in the composition and operation of all ecosystems, as well as an increased chance of animal extinction. The findings show that climate change will have an impact on biodiversity, among other things, by altering lifecycles, developing new physical features, shifting habitat and species distribution, and increasing the frequency and severity of pest and disease events (Hui, 2013; Sintayehu, 2018). Figure 1 illustrates the impact of climate change on biodiversity. Global warming will have an impact on forest species, both through habitat shifts and in direct reaction to temperature rises, precipitation variations, and severe weather events (Sarkar, 2012). Species extinction and relocation cycles have been triggered all over the world as a result of climate change. According to current climate projections, further environmental change will occur in the next decades (IPCC, 2013). Due to stresses and biological behaviours, climate change is also thought to be a significant driver of habitat alteration and degradation.

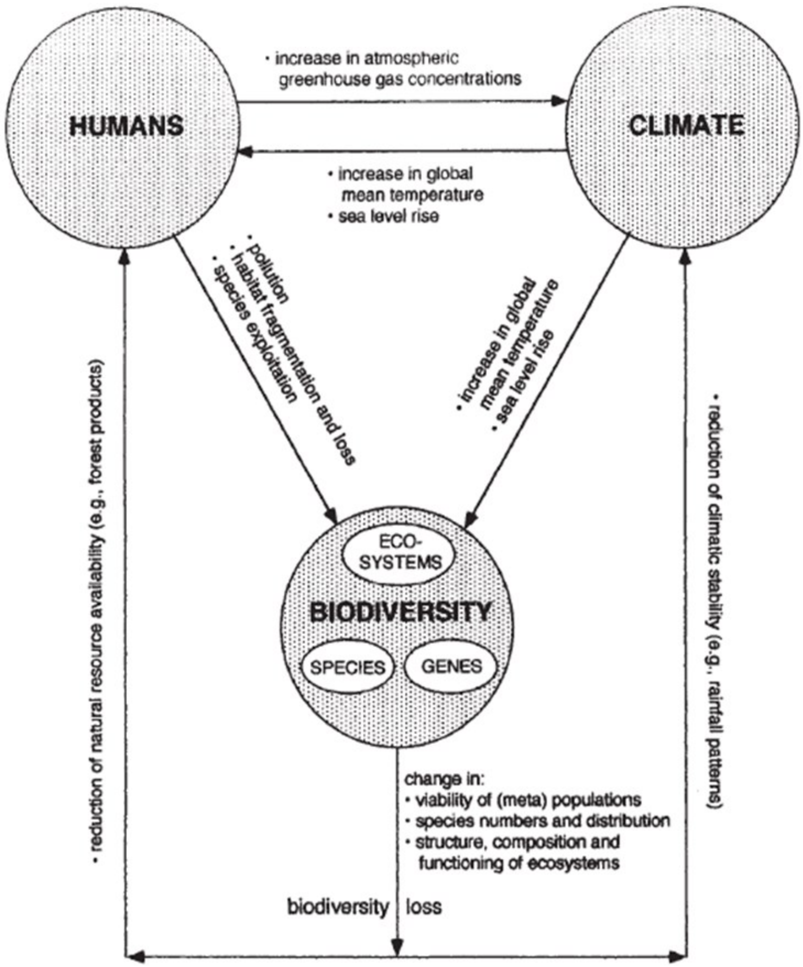

Figure 1. Effect of climate change and human interference on biodiversity (Adapted from Kappelle *et al*., 1999).

Effect of climate change on biodiversity

Biodiversity and ecosystem services based on biodiversity are climate-sensitive by definition. As the temperature rises and the planet warms, regional circumstances are impacted in a variety of ways. As the climate continues to change, there appears to be an impact on biodiversity loss. As a result of such effects, the composition and distribution trend of ecosystems and ecological services (Figure 2), on which human civilizations rely, are altered. Warmer temperatures cause greater evaporation, resulting in more rain and snowfall. The increased precipitation, on the other hand, is distributed unevenly, resulting in greater rainfall in some regions and dryness in others. Portions of South and Southeast Asia are experiencing heavy monsoon rains and sea level rise, while parts of southern Africa and the American Southwest are experiencing catastrophic droughts and crop failures. Dense snowstorms, hurricanes that are substantially larger, more violent heat waves, and intense rainstorms with accompanying flash flooding are all becoming more prevalent across the world (IFAW, 2013). Reduced snowfall and decreasing glaciers in the mountains result in less melted snow flowing into rivers, streams, and lakes for fish and animals, as well as less water accessible for drinking and agriculture (Palita, 2016).

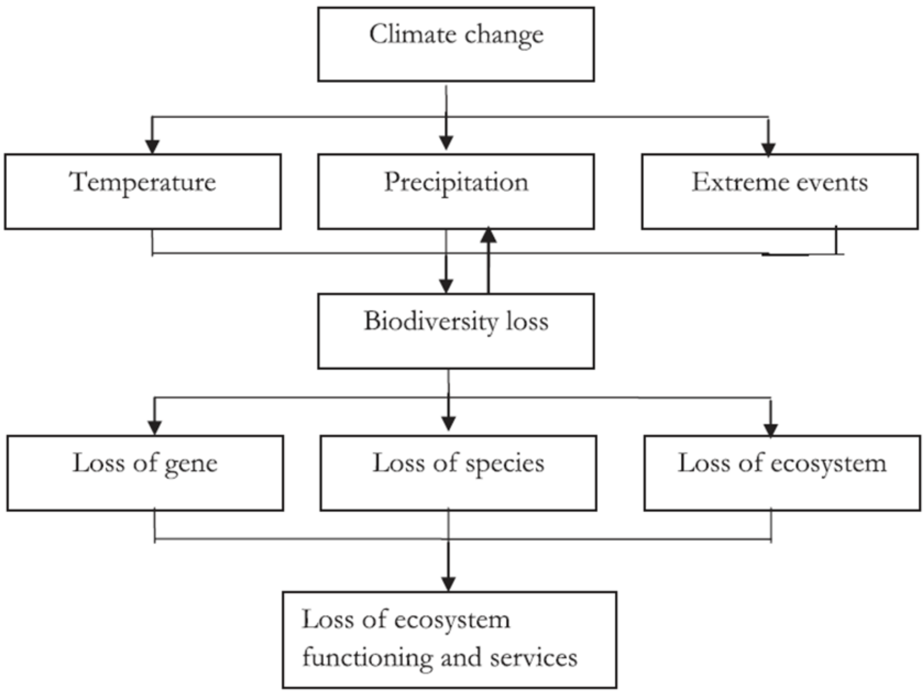

Figure 2. Impact of climate change on biodiversity and ecosystem loss (Adapted from Sintayehu, 2018).

Due to disturbance and competition from invasive species, species migration is presently on the rise and is likely to continue to have an influence on aquatic, land-based, and freshwater ecosystems (Wernberg *et al*., 2011). Many creatures, including the blue whale (*Balaenoptera musculus*), polar bear (ursus maritimus), great white shark (Carcharodon carcharias), ringed seals (pusahispida), and others, would begin to decrease and finally perish due to a lack of food and crucial alterations in sea-ice ecosystem interactions. Environmental changes such as change in temperature causes life forms to respond physiologically by following an optimal curve in which productivity (e.g., metabolic rate such as photosynthetic activity, rate of growth) is maximised under ideal conditions and survival is limited to a specific temperature range. Increased metabolic rates are considered to be caused by a drop in temperature below the minimum. Physiological rates (enzyme response, respiratory rate, food absorption, production, and growth) increase as a result, with the slope of the rise varying per organism. This physiological reaction can change phenology, which refers to all life-cycle activities that take place over time, such as larval development, hibernation season, migration to winter or summer habitats, and so on. Increases in metabolic rates are linked to increases in nutritional requirements, which means certain animals may need to eat more food or prey to fulfil their increased energy needs. As a result, if competing species display significant variations in competitive adaptation over a temperature gradient, competitive supremacy will shift along a small temperature differential.

Effect on terrestrial life

Animal and bird populations are declining as a result of changes in the environment and the eco-system. 150 bird species have already gone extinct in the previous 500 years, and one out of every eight species is currently endangered (Mooney *et al*., 2009). Any animal's initial response to a changing climate is to relocate in order to preserve ideal climatic circumstances, a process known as range shifts. At the colder poles, species are shifting polewards, whereas range boundaries are shrinking at the hotter range border, where temperatures are no longer viable. Land-based species are moving to higher elevations, where the temperature is cooler. Warming temperatures harm heat-sensitive plants (Welbergen *et al*., 2008), resulting in an increase in thermophilic species concentration (Reid, 2006) and shifts in species diversity trends (Roder *et al*., 2010). Warmer winters and higher seasonal heat levels, for example, are thought to have contributed to the mountain pine beetle (*Dendroctonus ponderosae*) epidemic's extreme severity and size in British Columbia's pine forests (Carroll *et al*., 2004). Because different species react at differing rates and to variable degrees, fundamental relationships between species are frequently disrupted, and new interactions develop. These anomalies will result in the development of new biotic species and significant changes in ecosystem functioning, with far-reaching and often unanticipated consequences for both ecological and human populations.

As a result of increased temperature in various areas, changes in the distribution of numerous animals have been detected. Warmer temperatures, for example, have resulted in an upslope shift in alpine bird habitat in Italy. Several habitats are anticipated to merge with ski-industry-friendly locations, creating conservation challenges for several bird species (Brambilla *et al*., 2016). Climate change has also affected the northward and altitudinal movement of bark beetles in North America. Increased temperatures and droughts make trees more susceptible to defoliators and bark beetles, increasing the intensity of pest infestations, which might have an impact on the ecosystem by increasing fuel loads and fire occurrence at high latitudes (Cudmore *et al*., 2010). Climate change alters the location, pattern, and density of terrestrial vegetation, resulting in higher average temperatures and a longer growth season. Changes in vegetation exacerbate climate change by influencing albedo, biomass, and evapotranspiration (Pearson *et al*., 2013). Drought and forest fire vulnerability may also increase as a result of climate change. In the future, it is predicted that tropical and semi-tropical forests and grasslands, which are rich in biodiversity and provide water management, carbon sequestration, nourishment, and timber, among other ecosystem services, would be converted at a faster rate (Harley *et al*., 2006). Over a 30-year period, spring leaf unfolding and fruit maturation patterns changed by 2.5 and 2.4 days every decade, respectively (Mooney *et al*., 2009).

Effect on aquatic life

Ocean acidification and temperature increases, more frequent and severe weather events, and changes in oxygen levels or deoxygenation procedures are some of the most immediate impacts of global warming on the marine ecology (IPCC, 2007). Nitrogen deposition, warming, precipitation variations, and changed runoff patterns are all major threats to freshwater systems worldwide (Woodward *et al*., 2010). Global warming has had a substantial influence on marine ecosystems, resulting in habitat loss and the introduction of invasive plant and animal species, as well as increased heat, acidity, pollution, and massive nutrient runoff into water (Mooney *et al*., 2009).Climate change poses the greatest danger to corals, sea grass, mangroves, salt marsh grasses, and oysters, which provide habitat for hundreds of other marine species (Harley *et al*., 2006). Coral reef biodiversity has already suffered as a result of rising water temperatures (Leahy, 2007). Increasing temperatures may affect changes in the structure of different plankton functional groups (Polovina and Woodworth, 2012).Climate change and weather patterns, according to a study conducted by Jackson (2008) in coastal estuaries, have resulted in the loss of 80 percent of the largest species, such as sharks and blue whales, 90 percent of oysters, 65 percent of sea grass, and 67 percent of wetlands. According to numerous studies, global warming causes organisms to alter their ranges in the ocean, with cooler water at deeper depths. Turan *et al*. (2016) utilised purse seiner, trawler, and trammel nets to examine surface water temperature change, as well as the composition and distribution of biodiversity, throughout Turkey's Mediterranean, Marmara, and Black Sea coasts for 41 years. Researchers found that surface sea water temperatures have risen by 1.5 to 3 °C in all seas, compelling native species to live with alien species. A total of 74 alien fish species have been discovered in Turkish waters (Figure 3). Demersal fish in the North Sea have migrated deeper as temperatures has increased. Smaller, less abundant southern species have migrated southwards, whereas thermally specialised fish have moved northwards (Dulvy *et al*., 2008). In response to rising water temperatures in Finland, the northern pike expanded its territory, whereas Atlantic salmon, an anadromous cold-water fish, dropped in number.

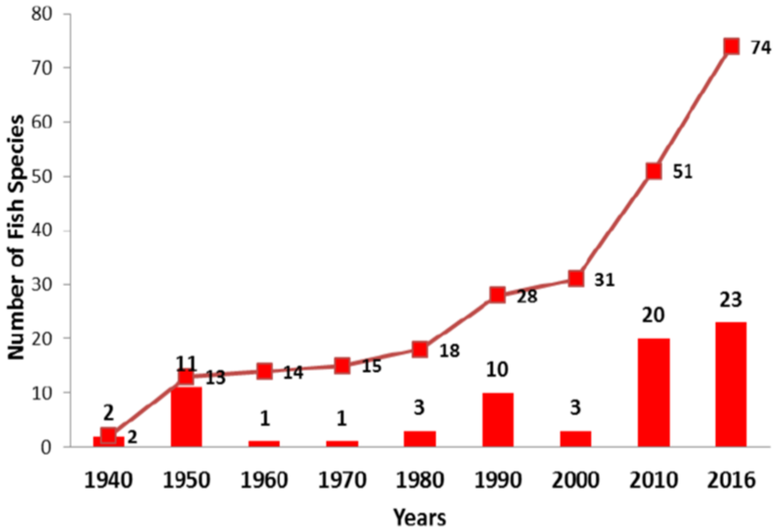

Figure 3. Graph indicating trend of alien species of fishes in waters of Turkey (Adapted from Turan *et al*., 2016).

Effect of climate change on agriculture

Temperature, sunlight, and water are the major regulators of agricultural development; therefore, climate change has a direct influence on agriculture. While certain aspects of climate change, such as a longer growing season and warmer temperatures, may help agriculture flourish and produce more, others, such as reduced water availability and more frequent severe weather events, may have negative repercussions. Climate change has an impact on plant development and productivity by increasing unpredictability in rainfall patterns, heat stress, pest and disease invasion, and crop cycle shortening. The influence of climate change on agriculture is predicted to cause havoc on certain parts of agricultural systems while also presenting possibilities for development. Shifts in the average climate away from present conditions may need changes to current practises to maintain production, and the optimal cropping strategy may need to be altered in some situations. Agricultural production, farm revenue, and food security may all be affected by raised temperatures during the vegetative season (Battisti and Naylor, 2009).

Varying plants have different temperature sensitivity. Crop adaptability and production are projected to grow and spread northward in the mid- and high-latitudes, particularly in cereals and cold-season seed crops (Maracchi*et al*., 2005; Tuck *et al*., 2006; Olesen *et al*., 2007). It was predicted by the IPCC (2001) that wheat yields will decline by 5-10% for every 1°C drop in temperature, and also that South Asian agricultural production might plunge by 30 percent by the twenty-first century. India's agricultural productivity is expected to drop by 40% by 2080. Temperature rises, according to the

Intergovernmental Panel on Climate Change (IPCC), will destabilise wheat-growing countries, putting hundreds of millions of people on the edge of famine (IPCC, 2007). A small change in average annual rainfall might have a big impact on a region's output. The monsoon rainfall pattern, both geographically and temporally, is critical for Indian agriculture (Kumar *et al.*, 2004). Asada and Matsumoto (2009) looked at the relationship between district-level crop output statistics (rainy season 'kharif' rice) and precipitation from 1960 to 2000.In a number of scenarios, different locations were shown to be sensitive to precipitation extremes. Crop productivity in the upper Ganges basin is linked to total precipitation throughout the relatively short growing season, rendering it sensitive to drought. The lower Ganges basin, on the other hand, was susceptible to pluvial floods, but the Brahmaputra basin saw an increasing impact of precipitation fluctuation on crop production, particularly during drought. Climate change has a direct impact on crop evapotranspiration (ET). Rising temperatures in Rajasthan's arid areas are projected to result in a 14.8% increase in overall ET consumption (Goyal, 2004). According to the study, even a slight increase in ET demand due to global warming will have a bigger impact on Rajasthan's dry zone ecology's vulnerable water supplies (Goyal, 2004). As a result, climate change will affect soil moisture, groundwater recharge, the frequency of floods and droughts, and, eventually, the water table at various locations (Huntington, 2003; Eckhardt and Ulbrich, 2003; Allen *et al*., 2004).

Assessment of climate change impact on biodiversity

When it comes to dealing with global climate change, the most pertinent concern is quantifying biodiversity potential. Nunez *et al*. (2019) conducted a meta-analysis of studies that used bioclimatic models and climate-change scenarios to quantify the sensitivity of terrestrial ecosystems to climate change, including global mean temperature increases of up to 6°C by 2100, along with related climate variables like precipitation change above pre-industrial levels. Two efficacy measures for measuring biodiversity changes were created using the data of 97 research. These metrics are the fraction remaining species (FRS) and the fraction of remaining area (FRA) with the appropriate climate for every single species. At moderate temperature levels (e.g., 1-2 °C), the study found that species cannot disperse or adapt, and that a significant decrease in their original biodiversity is predicted. Following the predicted climatic change, FRS is calculated as the average of ratios between the residual species number and the initial species number in each part of the map of the research region.

$$FRS = \frac{1}{n}\sum_{i=1}^{n}\frac{S_{di}}{S_{oi}} \quad (1)$$

Where,

S_{di}=Expected number of species remaining in grid cells i following climate change

S_{oi}= number of species in grid cell i during initial condition

n = total number of grid cells.

FRS is a relative index that ranges from 0 to 1, with 0 indicating no original species and 1 indicating all original species are present. FRS decreases when the climate in one of the grid cells within the study region becomes unsuitable for a species. FRS depicts species' reactions to climate change on a local level. FRA calculated as the ratio between the appropriate original and surviving climatic area is computed for each species.

$$FRA = \frac{1}{S}\sum_{J=1}^{S}\frac{A_{di}}{A_{oi}} \quad (2)$$

Where,

A_{dj}= remaining suitable climate area for species j after climate change

A_{oj}= climate area for species j in original situation before climate change

S = number of species

FRA is also a relative index that ranges from 0 i.e., no initial appropriate climate area to 1 i.e., unchanged climate area.

Another study conducted by Habibullah *et al*. (2019) employed the improved threatened species-climate change equation to experimentally analyse the impact of climate change on the number of threatened species:

$$\text{threatened species}_{ji} = \alpha + \beta\text{naturaldisaster}_i + \gamma\text{temperature}_i + \varphi\text{precipitation}_i + \delta\text{realGDP}_i + \theta\text{government effectiveness}_i + \epsilon_{ji} \quad (3)$$

where β, γ, ϕ, δ, and θ are the parameters coefficients to be estimated and final term indicates the error. Although there are other methods for deriving conclusions, such as existing palaeontological or existing data, experiments, observations, and meta-analyses (Lepetz *et al*., 2009), ecological modelling is the most commonly used methodology for predictive research. According to Crick (2004),despite the fact that many bioclimatic models are very accurate (Williams *et al*., 2003) the majority of research into the effects of climate change on organisms still rely on predictive large-scale models to cope with abiotic data from satellite sensors. There are three fundamental approaches for estimating biodiversity loss: future changes in species range or extinction, future changes in species diversity, and future changes in species diversity. Furthermore, all three modelling approaches have mostly focused on one axis of response (space change), disregarding the importance of the other components (Bellard *et al*., 2012). Existing species ranges are linked to a number of climatic variables using Bioclimatic Envelope Models, which define each species' climatic niche (envelope). The niche may then be forecast for various future temperature scenarios to determine the species' suitable climatic space's possible redistribution. Considering species–area relationships (Thomas *et al*., 2004) or IUCN status, the likelihood of extinction may then be evaluated using a number of approaches (Thuiller *et al*., 2005). Models of Dynamic Vegetation (DVM) anticipate changes in vegetation and associated biogeochemical and hydrological cycles in response to climate change. DVMs use time series of meteorological data (e.g., temperature, precipitation, humidity, sunshine days) and topography and soil characteristics to mimic monthly or daily dynamics of biological processes.DVMs are currently of limited use for directly projecting biodiversity variations, but when combined with extinction models, they give an estimate of the risk of extinction of species on a regional or worldwide scale (Van Vuuren *et al*., 2006). The species–area relationship (SAR) is an empirical correlation seen between a species' population and its area (Thomas *et al*., 2004). Extinction risk is calculated by observing that extinction risk increases with decreasing range and population size as a direct result of habitat loss or climate-induced area shrinkage. SAR methods may underestimate or exaggerate the threat of extinction based on species' capacity to survive in low populations or adapt to new environments, and they may also be unable to define a timeline for extinctions (Chevin *et al*., 2010). DRR (dose–response relationship) models can generate empirical correlations between the relative significance of global variables and changes in species decline using observable data and experiments. The most common use of species distribution modelling (SDM) has been to anticipate the impact of climate change on the global distribution of one or more species at a time (Thuiller, 2003).Such predictions may be useful in developing conservation strategies for species of critical concern, but they are less applicable to overall biodiversity planning. SDM is a powerful method for spatially anticipating the explicit impact of climate change on biodiversity.

Innovative concepts and techniques must be developed in order to adapted successful mitigation and remediation solutions on a medium and small scale. Sound is one of the most intriguing alternatives since it is an important route for intraspecific and interspecific communication across hetero- and homoeothermic groups of animals. The study of sound from an ecological standpoint is known as eco-acoustics (Sueur and Farina, 2015). Eco-acoustics has been widely used in biodiversity assessments, such as habitat assessment (Bormpoudaki *et al*., 2013), habitat quality variations (Piercy *et al*., 2014), habitat selection (Figueira *et al*., 2015), distribution and dynamics (Risch *et al*., 2014), population density (Lucas *et al*., 2015), and species invasion (Both and Grant, 2012). Eco-acoustics and related sub-disciplines are critical subjects of study and application for the complex issues raised by climate change. When coupled with other remote sensing methods, the expansion of eco-acoustic approaches provides a powerful new methodology for exposing behaviour of species and environmental systems in the context of climate change (Krause and Farina, 2016).

Impact on human life

As a result of climate change, temperatures rise, ice melts, and severe other weather events become more prevalent. Water-borne diseases like cholera and typhoid, tropical and vector-borne diseases like malaria, dengue fever, and plague, as well as rodent-borne diseases such as plague, are caused by extreme events like floods, droughts, and storms that force people to flee from their homes. Temperature changes have caused an upslope shift in malaria distributions in Ethiopia and western Colombia, resulting in an increase of average malaria cases in warmer years. Previously malaria-free high-elevation regions in Ethiopia are now within the disease's viable range. Similarly, in Colombia, temperatures fluctuated without a consistent warming trend, and high-altitude malaria incidence shifted drastically in response to temperature changes (Siraj *et al*., 2014). Another example is the outbreak of Vibrio, a bacterial aquatic disease, across northern Europe. Changes in sea surface temperature are a source of concern in the Baltic (Baker-Austin *et al*, 2013). The rising sea level has already swamped a number of islands, and millions more migrants throughout the world will soon be in need of refuge. Saltwater entering fresh water sources has polluted the land and may soon impose a food safety concern.

Mitigation measures

Biodiversity is affected by climate change through changes in distribution, species mobility, invasions of alien species and phenological shifts, such as in breeding periods, migration seasons, etc. Even small climate changes might cause the extinction of a few vulnerable or sensitive species. In the face of climate change, the only way to prevent environmental degradation is to reduce human pressure. Clearly, greenhouse gas emissions must be drastically cut and biodiversity loss must be prevented. Understanding how plants, animals, and organic matter interact is essential for preserving the ecosystem's balance and promoting conservation and preservation of the environment through the establishment of biosphere reserves, increased afforestation and reforestation, and enhanced agro-forestry. The taxation of carbon emissions and/or subsidies on emissions that favour renewable energy sources are two additional important actions to reduce the use of fossil fuels or to boost sink absorption (Omann *et al.*, 2009). Aside from that, there are also legal provisions for voluntary agreements and technological standards, as well as support for improving energy efficiency and road pricing (IPCC, 2007). Strategies for mitigating greenhouse gas (GHG) air concentrations help to stabilise or reduce GHG air concentrations to safe levels for the climate system (Kimmel, 2009). Diversity-focused adaptation and mitigation approaches improve ecosystem security while reducing the impact on natural and human ecosystems. The integration of biodiversity and ecosystem services into an overall adaptive strategy may bring cost-effectiveness and co-benefits in social, economic, and cultural aspects, as well as make substantial contributions to the protection of biodiversity and ecosystem services. Additionally, conservation of biodiversity might be used to counteract the detrimental impacts of climate change on biodiversity, while simultaneously enhancing ecosystem function. The beneficial impacts of biodiversity may be employed in forest management strategies to reduce the negative effects of climate change on ecosystem functioning, or to improve the positive effects of climate change on ecosystem functioning (Figure 4). Although the rates and severity of climate change are becoming increasingly difficult for natural adjustment, management and conservation strategies that maintain and recover biodiversity may be expected to mitigate some negative impacts from climate change.

Conclusion

This decade's environmental worries have centred on climate change, therefore it's imperative that people become aware of the problem and take action. When it comes to species occurrence and variety, even a modest and moderate warming would have complicated consequences, including disturbing ecological functions. There is a rapid increase in emissions of greenhouse gases, which have a negative

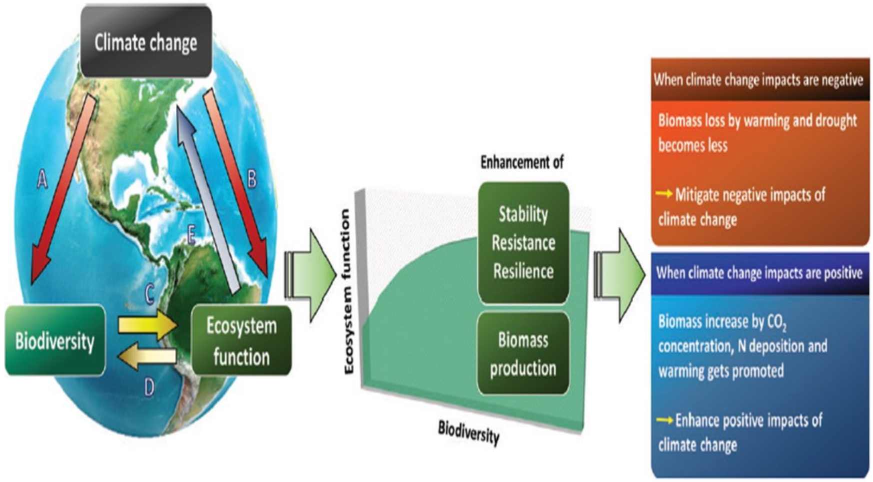

Figure 4. Diagram depicting negative and positive effects of biodiversity change on climate change (Adapted from Hisano *et al*., 2018).

impact on the population and ecosystems and cause climate change. Biodiversity has already been lost as a result of human activity, and goods and services that are essential to human well-being may have been affected as well. Direct or indirect, climate change has had and will continue to have a negative effect on biodiversity. It is possible that these implications will have major negative effects on important ecosystem services, such as agricultural and animal production, disease regulation as well as the climate. One of the main effects of climate change is the modification of water resources and crop production. Systematic study on how climate change affects agriculture, forestry, animal husbandry and aquatic life must be strengthened immediately. Monitoring programmes that provide useful information for conservation and ecosystem-based management are needed to understand species' potential to adapt to climate change and also to the ecosystem characteristics that encourage resilience. As a country, we should employ all of our resources and efforts to reduce greenhouse gas emissions in order to combat global warming and natural disasters. Good government planning and policy execution will help mitigate biodiversity loss.

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Chapter
[8]

Impacts of invasive alien plant species on biodiversity in the regions of Western Himalayas, India: An overview

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Abstract

The Western Himalayas regions are one of the riches repositories of the plant diversity in India. The spread of invasive alien plant species across Himalayan range causes loss of biodiversity including species extinction and change in the ecosystem functioning. These exotic plant species differ from their native area, based on their requirements, mode of resource asset and consumption may lead to the change in the structure, profile of the soil as well as the nutrient content. This results in adverse impacts on the biodiversity and ecosystem. However, various studies have been performed in documenting the ecological impacts of invasive species but there is a lack of understanding in regards of their economic importance, medicinal values, and livelihood considerations and in assessment the risk on human health. Present paper showcased some invasive alien species which are common and becoming threat for the forest zones and alpine regions in the Western Himalayan states of India.

Keywords Biodiversity, Himalayas, Invasive Alien Plant Species, Western Himalayas

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Introduction

The alien plant is also denoted as foreign, introduced, exotic, non-native and non-indigenous. These plant are those which had been introduced by human deliberately or else through human activity or unintentionally from one area to another. This alien plant gets slip away from its environmental habitat and starts its development and reproduction on its own in the regional flora is which considered as naturalized species. The invasive alien species are naturalized alien which has are successful that it can scattered and spread with the regional flora as well as relocate the native biota by threatening the valued environmental, agricultural or personal resources by the damage it causes are considered invasive. Biological interference has been identified as a significant contributor to global environmental change and is a major cause of degradation or depletion of native biodiversity and ecological services. The invasive alien species are plants, animals, or other organisms which come up to places outside their natural area giving a negative impact. It has seen for the past few years that invasive alien plant species have caused several menaces to the native biodiversity, ecosystem services and also deteriorated the environmental quality as well as human health (Kueffer, 2017; Jones and McDermott, 2018; Bartz and Kowarik, 2019). The rate of biological colonization has increased in all habitats and environments as human migration and foreign trade have increased. The detrimental effect of invasive species is compounded further by ongoing climate change, which is expected to increase both the extent and severity of biological invasion (Simberloff, 2000).

Biological invasion could also be thought-about as a variety of biological pollution and major factor on international amendment and one in every of the foremost causes of species extinction (Mooney and Drake, 1987). However, notably, in this respect Global Assessment Report on Biodiversity and Ecosystem Services of United Nation and human health (Pyšek and Richardson, 2010; Stone *et al*., 2018; Jones and McDermott, 2018; Jones, 2019). In this present scenario United Nation an Inter-governmental stage for biodiversity as well as ecosystem services predicted that about nearly, 1/5th of the Earth's surface and even total biodiversity hotspots present around the world are in danger due to foreign aggressors (IPBES, 2019). Invasion issue can be more often notices in developed countries as compared with low income nations. Therefore, the hotspots of invasive alien plant species in developed nations includes Australasia, European Union and North America, Asia Pacific and African regions too. Currently, invasive alien plant species professed as main motorist for the biodiversity loss (Seebens *et al*., 2018; IPBES, 2019). But these invaders are not only responsible for loss of biodiversity there are others drivers too including anthropogenic activities, pollution, habitat fragmentation, climate change, over exploitation are some major threats to natural biodiversity.

India is known as unique 17 mega biodiversity nation of the world. The country has a vast phytogeographical area and edaphic conditions that offers the lush growth for countless fauna and flora (Chaudhry *et al*., 2011). The country poses diverse ecological conditions which provide a platform for arise of a new alien species. The Himalayas is known for its rich biodiversity and forest ecosystem that provides a high value of environmental service. The region has expanded landforms and climatic zones which uphold a wide range of vegetation (Rana *et al*., 2010; Khanduri *et al*., 2017). The various change in the climatic conditions and ecological change lead to the infringement of the area by any other new alien species. Raizada *et al*. (2008) published that CBD known as Convention on Biological Diversity stated that invasive alien plant species is the second largest cause for the loss of biodiversity worldwide and inflicts high prices on forestry, agriculture, and water ecosystems.

The Himalayan mountain range are one of the most endangered and exquisite habitats of the world, consisting of enormous biodiversity that provides significant ecosystem services (Kumar *et al*., 2020). For last few years' scientists and policymakers has noticed that native diversity is under pressure all over the globe due to foreign invaders which have become greatest threat.In fact, one sixth of the world's ground surface habitat are enormously unsafe due to attack of alien species, which include large part of high income nations and global hotspots diversity (Early *et al*., 2016). The invasive species are non-indigenous species and they show adverse consequence which can be economically or environmentally especially at those areas where these species are being introduced, either unintentionally or intentionally, outside their distribution pattern (Masters and Norgrove, 2010). Around 0.5–0.7 percent of the world's tree and shrub inhabitants are now a days invasive outside to their native ranges (Richardson and Rejmanek, 2011).Invasive species are regarded as one of the main causes of biodiversity destruction, altering environmental resources and socioeconomic environments through a variety of mechanisms (Rai and Singh, 2020). The Convention on Biological Diversity (1992) identified biological invasion as a major cause of biodiversity loss, ranking second only to habitat depletion and ecosystem degradation.

Status and distribution of invasive plant species in India

India is known as mega diverse country since it covers 2.4 percent of the global geographical area and accounts about 8% of the world's species diversity (Khoshoo, 1996).There are about 90,000 animal species and 45,000 wild floras, with just roughly half of the geographical region investigated so far (MoEF, 2008). Nearly 40% of species considered as alien species are found in India's flora. Due to growing trade and travel via numerous ways, India is a megadiverse country that is rapidly globalizing, putting species at risk of invasion (Saxena, 1991; Singh, 2005). Invasive alien flora and fauna have been identified as a major cause of species extinction and endangerment in freshwater wetlands and aquatic environments. Some of the Indian research revealed that inland environments have a lot of non- native flora and fauna, as well as the ramifications of regional invasion (Arya *et al*., 2021). Reddy (2008) compiled the first catalogue of invasive alien plant species of India. Khuroo *et al*. (2012a, b) released a list of 1599 alien plant species belonging to 842 genera and 161 families with their native ranges and invasion status from India. About 471 invasive plant species were compiled by Inderjit *et al*. (2018). There are very few studies done from Indian Himalayan region on exotic species (Khuroo *et al*., 2007; Sekar *et al*., 2012; Jaryan *et al*., 2013; Sekar *et al*., 2015). Debnath and Debnath (2017), provided a comprehensive listing different kinds of foreign plant from Tripura, as well as facts on their intrusive life form, status, pattern, habitat, and source of introduction. This type of research, which provides updates on the status of the invasion, would be extremely beneficial in effective management.

The data on invasive species distribution is crucial for understanding the range of species shifts and comparing them across different time periods. The states of Western Himalayan region i.e. Himachal Pradesh, Jammu and Kashmir and Uttarakhand account 232,192,181 invasive alien species respectively. The studies done by some of the ecologist and taxonomist in Western Himalayan region are Khuroo *et al*. (2007) complied the invasive flora of Kashmir valley and Kaur *et al*. (2014) published invasive flora of Jammu. Jaryan *et al*. (2013); Sekar *et al*. (2015) listed various kinds of invasive species for Himachal Pradesh. Invasive alien flora of Doon valley was compiled by Negi and Hajra (2007) and updated listing of invasive alien species was published by Sekar *et al*. (2012).

Proliferation of invasive species in western Himalayan regions

The most proliferative alien plant species present in Western Himalayan region are listed in the (Table 1). The results revealed that *Ageratum conyzoides*, *Lantana camara* and *Parthenium hysterophorous*are the established invasive alien species that have flourished and effecting the biodiversity from Western to eastern Himalayan regions of India. The species including *Argemone Mexicana*, *Ageratina adenophora*, *Cassia tora*, *Rubus neivus* and *Sapium sebiferum* persist and proliferative in a larger area of western Himalayan regions. Therefore, such species should be given more emphasis to the flourished alien species, but also on the such invasive species which till now are not proliferated so that they can be prevented of becoming invasive to the areas. There are few such species which are confined to a certain area or state for example *Anthemis cotula* which only is reported from Kashmir Valley (Khuroo *et al*., 2008) and on the other hand *S. sebiferum* which has shown its proliferation only in Himachal Pradesh (Jaryan *et al*., 2013).

Influence of invasive plant species

The above invasive alien species cause a wide range of impact on different classes of diversity, richness, crop fields, loss of nutrient component and environmental services to larger extent (Bhatt *et al*., 1994; Wilcove *et al*., 1998; McKee *et al*., 2004; Reshi *et al*., 2008; Vila *et al*., 2010; Huddle *et al*., 2011). Some of the studies have also shown that due to growth and development of invasive species can lead to genetic variation in regional populace through hybridization and also often obstructs in plant pollination interaction (Vila *et al*., 2000; Schweiger *et al*., 2010). The studies done globally on invasive plants has revealed that there is low richness and diversity of local plants in the invaded occupied sites but on other hand it is also increased the primary production in those localities (Vila *et al*., 2000). Kosaka *et al*. (2010) reported that previously, the invasive alien plant species proliferate mainly along way side or open forest cover areas or boundaries in the Indian Himalayan region. In the last few decades it has been seen due to fast urbanization through forest range so many of alien species have started occupying woodland and mountainous ecosystems. The investigation and studies done by some of the researches have revealed that these invasive alien plants species pose numerous impacts/ effects on the

Table 1. Dominant invasive alien plant species in Western Himalayan Region of India.

Plant Species	Family	Native country	Life form	Pattern	Utilization	Habitat	Mode of Introduction	State
Argertum conyzoides L.	Asteraceae	Tropical America	H	A	M	AL,WL	O	J&K, HP & UK
Argemone mexicana L.	Papaveraceae	South America	H	A	M	W, RS	Ui	J&K
Ageratina adenophora (Spreng.) R.M. King & H. Rob.	Asteraceae	Mexico and Central America	S	P	M	W, RS	O	UK
*Anthemis cotula*L.	Asteraceae	Mediterranean region	H	A	M	W	O	J&K
Cassia tora L.	Caesalpiniaceae	South America	H	A		W	Ui	J&K
Lantana camara L.	Verbenaceae	Tropical America	H	P	M	F ,RS, AL	O	J&K, HP and UK
Sapium sebiferum (L.)Roxb.	Euphorbiaceae	China	T	A	M, Ag, Sb	DS, RS, AL	O	H.P.
Rubus niveus Thunb.	Rosaceae	India, China & South Asia	S	P	M, FP		O	J&K and UK
Parthenium hysterophorus L.	Asteraceae	North America	H	A	Not known	W,RS, AL	Ui	J&K, HP and UK

Table 2. Studies on impact or effects of invasive alien species.

Impact /effects	References
• Replacing medicinal plants and fodder grass	Bughani and Rajwar (2005)
• Constraint of seed growth and development	Bhardwaj *et al*. (2014)
• Preferring other invasive species over endemicspecies	Dobhal *et al*. (2011)
• Adapt of natural habitats	Dar and Reshi (2015)
• Some of the studies showed the effects on natural environment, but others mainly concentrated on agricultural ecosystems	Batish *et al*. (2007, 2009); Katoch *et al*. (2012)
• Dropping in nutrient level of the soil	Bhatt *et al*. (1994)
• Depletion various ecological parameters of native species like frequency, density and abundance	Tripathi *et al*. (1981);Kandwal *et al*. (2009)

native diversity and ecosystem which are as follows in the Table 2. In Indian mainland is mainly occupied by *Parthenium hysterophorous* and pest-ridden areas by species which is assessed as nearly 5 million acres (Kohli *et al*., 2006). Dobhal *et al*. (2011) reported that Amongst many invasive alien species present in Indian Himalayas viz. *A. adenophora*, *A. conyzoides*, *L. camara* and *P. hysterophorus* are causing the negative impact on the floral diversity to a higher extent due to wider spread over Indian Himalayan regions. The studies have shown that *P. hysterophorus* is the one of the toxic or poisonous weed which is supplanting the native population and causing major health related problems in humans in this region. In the same way, the region is also effected by another species.

Lantana camara is stated to infringe upon vast area of lands, particularly in the lower part of Himalayan foothill forests, where it effectively replaces the underground layer of forest vegetation as well as also decrease the growth and development of trees (Kohli *et al*., 2006; Negi *et al*., 2013). This toxic wild plant is also responsible for the decrease species richness to 28.4% of invaded regions and approximately 63% damage to basal area of vegetation in invaded regions as related to non-invaded whereas, there is negative effect of structural growth and function of plant vegetation (love *et al*., 2009; Dobhal *et al*., 2010). *Ageratina adenophora* species mainly present in the moist areas, along roadside and forests of Garhwal Himalayas and other Himalayan region giving a negative impact on the plant diversity and crop land by increasing advantage through allelopathic affects and to some extent it also changes the soil microbial populations (Dhyani, 1978). Tripathi and Yadav (1982) stated that this invasive species is abundantly found growing in the Eastern Himalayan states. *A. adenophora*is also reduces the crop production by falling the seed germination of the vegetation, it has also observed that this species is also responsible for the replacement of local grasses from the grassland ecosystems (Kosaka *et al*., 2010; Katoch *et al*., 2012; Datta *et al*., 2017).

Ageratum conyzoides alien species is known to invaded agricultural and crop fields and causing decrease the production of major crops yields by effecting the seed germination; varying soil properties and also responsible in the species reduction in terms of richness in the overspread areas (Kohli *et al*., 2004;

Batish *et al*., 2009, Dogra *et al*., 2009; Katoch *et al*., 2012; Sekar *et al*., 2012). The Kashmir valley known to be one of the biodiversity hotspot of Himalayan region (Allaie *et al*., 2005), where invasive alien *Anthemis cotula* is spreading at a faster rate and becoming one of the major threat for the native diversity and environment. The invasion of ruderal habitat by this alien species has made extended conscription pattern abetted by disturbed habitat, favourable physical factors like temperature, moisture, light and nutrient level, high populace size that can be observed even afterward of seedling mortality and allelopathic action of its aqueous foliage percolate (Allaie *et al*., 2006; Shah and Reshi, 2007). *Argemone mexicana* is a common alien species found growing everywhere along the roadside in India. The seeds of the plant bear a resemblance to the seeds of mustard (*Brassica nigra*) it can be adulterated by argemone seeds, rather it is poisonous. There are many important examples of katkar poisoning which have been reported from India as well other countries of the world. There was one such instance with occurred as a major outbreak in India in 1998 where 1% adulteration of mustard oil was mixed with argemone oil and caused clinical disease (WHO, 2006). *Cassia tora* is innate to tropical South America and its was introduced in India nearly in initially 1960's (Singh, 1979; Raghavan, 1980; Reddy, 2008). It has been observed in some of the studies that *Cassia Spp*. usually found growing in scattered clumps, in the interim water logged areas as well as along roadside in pasture land and frequently this species is found growing with the diverse vegetation (Bolde and Dhulap, 2019). *Rubus niveus* the most dominant alien woody tree species in different regions of India. This species spread speedily and grow faster, utilized accessible resources and influenced larger ecological flexibility than native species in the area (Singh *et al*., 2006). *Sapium sebiferm* it is commonly recognized as tallow tree and is also known to be as most trouble invasive tree species in the world. In the Western Himalayan region especially Himachal Pradesh is found growing abundantly and in few areas it can be seen influencing the wetland as well as mesic habitat. As *S. sebiferm* favours moister areas to increase dominance against innate vegetation (Jubinsky, 1993).

Management outlook of invasive alien species

In the fifth IUCN World Park Congress (2003) mentioned that management of invasive alien plant species could be a precedence matter and its necessity to be standard into all the aspects that management of the forests additionally as all protected areas. The matter in context of managements of the protected areas was highlighted throughout IUCN World Conservation Congress of 2012 and IUCN World Parks Congress control throughout 2014. The management of invasive species is considered to be expansive and high labour cost which have been an interruption in management of these invasive species. Eradication and biological control studies have shown that eradication methods for invasive species are effective only if they are completed at initial stage of propagation (Zanden *et al*., 2010). To some extent eradication process of well-established invasive species may be reason for the release of one more earlier suppressed non- invasive species to invade a particular area. Hence, eradication process needs a lot of monitoring of the specific areas where these invasive alien species are proliferating so, further invasion can be prevented (Caut *et al*., 2009). Whether, invasive alien plant

species have positive or negative ecosystem services however it ought to be clearly recognized to clarify its cost-benefit which can be useful for the policy makers and stakeholders (Zengeya *et al*., 2017; Everard *et al*., 2018; Shackleton *et al*., 2019). The policy makers need to undergo many aspects of obliteration like price of eradication, likelihood of success and for an instance if failure happens then more what impact can intruder will cause to a selected space that may be regeneration of invasion species, aid different invasive species (Zanden *et al*., 2010). For eradication of invasive species from Indian Himalaya region a obliteration was done in Jim Corbett National Park, Uttarakhand, with the help of cut root stock methodology beside with manual removal of *L. camara*, which is one of the a well-established invasive alien species in this region (Love *et al*., 2009). Further, to stop the regeneration of invasive species or any other secondary invasion by different invasive species, restoration of that area with native grass species was done and this experiment was beneficial (Babu *et al*., 2009).
Biological control measures are taken in several components of the globe, however not in India aside from toxic *Lantana camara*. The tries to manage infestation of toxic plant *L. camara* biologically by introduction of pest of the species was initiated in India in 1916 (Muniappan and Viraktamath, 1986). Ever since varied studies/ investigation are directed to manage the species by diverse pests for instance *Ophiomyia lantanae*, *Lantanophaga pusillidactyla*, *Teleonemia scrupulosa* etc., and for these pest the host plant is *L. camara* (Khan, 1944; Muniappan and Viraktamath, 1986). Invasive alien plants have a plus over the natives as a result of the run off their natural enemies from their native ranges. Thus, biological control of invasive species mistreatment co-evolved natural enemies has long been thought-about a secure, environmentally sound and price effective management tool it's one technique that's used either alone or together with alternative management choices. Moreover, it's usually extraordinarily successful and extremely value effective method (Moran *et al*., 2005; Messing and Wright, 2006).The systematic study on ecological role of invasive species should be conducted before the eradication process. On the other hand, biological control studies of invasive species cab be beneficial for improved control as well as management of invasive wild plants. Therefore, it requires proper monitoring for an enduring time for better management of the disturbed sites with well-established invasive species since long time with an effective management sustainable approach.

Conclusion

Among several invasive species including *L. camara*, *A. adenophora*, *P. hysterophorus* and *A. conyzoides*, *R. niveus, S. sebiferm*, *C. tora, A.* mexicana and *A. cotula* have been reported from Indian Himalayan states. These above species proliferated over large areas of India. The printed studies have shown the evidences that fast urbanization in the forms of construction of roads passing though forest and high–altitude ecosystem and extensive tourism in such areas have lead the increase growth rate of these invasive species. The Himalayan regions have rich and unique biodiversity, still it faces sever intimidations due to proliferation of invasive alien species and this evidence shows that these alien species are moving upwards in the higher altitudes of the Himalayan states. Widely distributions and fast proliferation of these species is menace for native biodiversity and ecosystems to the greater extent in near future. So, more emphasize must be given on these invasive species and some appropriate management strategies can be made for relating to plant invasion over Indian Himalayan regions. Recent advancement in the technologies like GIS and Remote sensing can help in the study and management of the invasive species. The impact of climate change can also be studied through these techniques.

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Chapter [9]

Indigenous knowledge in forest conservation, species diversity and stocking potential: A historical perspectives of northwest Tanzania

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Abstract

The study evaluated the current status (i.e., species diversity, regeneration, and productivity) of the community forests conserved under indigenous knowledge known as Ngitili of northwest Tanzania. We conducted a field study in 10 community forests using phytosociological approaches. Quantitative data were statistically analyzed using ANOVA, while the differences between mean was checked by LSD at $p < 0.05$ using SPSS software. Results indicated that, out of 10 surveyed community forests, 4 were highly threatened (40 %), 5 were highly disturbed (51 %), while 1 (9 %) was converted to other land use. A total of 66 plant species belonging to 54 genera and 27 families were recorded. Biomass production varied significantly between plants ($p < 0.001$). Lack of environmental education and anthropogenic activities pose a great challenge among community forests. Therefore, appropriate management interventions are highly required to rectify the situation for the sustainability of these forests.

Keywords Biodiversity, Deforestation, Traditional Ngitili, Kishapu-Tanzania

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Introduction

The use of indigenous and traditional knowledge in forest conservation and management among communities, particularly the northwest regions of Tanzania, has been practicing even before the colonial era (Malcolm, 1953; Dery *et al.*, 1999; Barrow and Mlenge, 2003). Some pastoralist communities, such as the Sukuma, the largest ethnic group in northwest Tanzania, set aside and retaining an area of standing vegetation from the beginning of the rainy season and opening it up for grazing at the peak of the dry season (Selemani *et al.*, 2012; Cazzolla-Gatti *et al.*, 2014). Other communities practicing vegetation conservation systems include the Himba (Namibia) and the Borana (Ethiopia), and Masai (Kenya) (Selemani *et al.*, 2012; Duguma *et al.*, 2013). The community forest and vegetation conservation system in the northwest of Tanzania is locally known as "*Ngitili*" (Malcolm, 1953; Dery *et al.*, 1999; UNDP, 2012). It is one of the local and traditional vegetation conservation systems among the agro-pastoral ethnic group in the Shinyanga region of Tanzania (Otsyina *et al.*, 2008; Buckingham and Hanson, 2015). The system existed as early as even before the colonial era (Duguma *et al.*, 2019). The indigenous knowledge aims to carter acute fodder shortage by providing a good time for vegetation recovery (Barrow and Mlenge, 2003; Treue *et al.*, 2014). Apart from its prominent roles, *Ngitili* contributes to improving a given environment's ecological conditions (Jama and Zeila, 2005). The system contributes more to species diversity and ecosystem services in the region, such as climate change mitigation through enhanced carbon sequestration (Duguma *et al.*, 2019). It also provides a fundamental source of fuelwood, thatch grass, water catchment, scenic beauty, and diversification of nutrition options (e.g., fruits, vegetables, mushroom, edible insects, wild meat, medication) (Monela *et al.*, 2005; Barrow, 2014; Chirwa, 2014). Apart from forest-based ecosystem services, the system improves households' economies that supplement agriculture income (Zahabu, 2008; Duguma *et al.*, 2013).

Therefore, *Ngitili* is considered an essential traditional strategy for forestry management, rehabilitation, and restoration in Tanzania. The recognition and incorporation of *Ngitili* in forest management came into existence in the early 1980s. The government revised its forest policy, emphasizing community participation in forestry management (Zahabu *et al.*, 2009; Treue *et al.*, 2014). It was subsequently reinforced in the Forest Act No.14 of 2002 (URT, 2002). Following the recognition of *Ngitili* as a traditional vegetation conservation system by the government in the 1980s. The sizes and number of *Ngitili* increased spontaneously from 600 to 18,607 ha from 1986 to the 1990s (UNDP, 2012). From 250,000 to about 500,000 ha in 2001-2004 (Monela *et al.*, 2005; Buckingham and Hanson, 2015). The system received international recognition as a means of restoring degraded lands and its contribution to forestry restoration, environmental conservation, and atmospheric carbon stocking (Monela *et al.*, 2005; Barrow, 2016; Osei *et al.*, 2018).

Historical perspective about *Ngitili* and conservation

Shinyanga region was initially being dominated by dense woodland and bushland with different tree species of the genus *Acacia, Brachystegia, Jubernardia, Albizia, Commiphora,* and *Dalbergia* (Monela *et al*., 2005; Otsyina *et al.,* 2008; UNDP, 2012). Other common plants were *Grewia, Balanites, Pterocarpus*, and *Afzelia* (Kamwenda, 2002). Dominant tree species were; *Acacia tanganyikensis, Acacia polyacantha, Afzilia quanzensis, Brachystegia species, Commiphora africana, Combretum zayeri,* and *Dalbrgia melanoxylon* (Kamwenda, 2002; Barrow, 2014). The forested woodlands provided fodder for livestock and basic needs such as food and fuel for the agro-pastoralists ethnic group in the region. Despite that, the dense forest was also a reservoir for the tsetse flies, transmitting a parasitic disease known as *trypanosomiasis* to both humans and livestock (Barrow and Mlenge, 2003; Duguma *et al*., 2019). Therefore, in the 1920s, the colonial authorities instituted a program through which local people were paid to cut down large woodland areas to eradicate the tsetse flies. The Sukuma people were happy with the order, not only for eradicating tsetse flies but also for opening up new grazing and agricultural land (Selemani *et al*., 2012; Buckingham and Hanson, 2015). Apart from the tsetse flies eradicating program of 1925 to 1960s, other programs that accelerated massive deforestation and land degradation includes; the villagization program of the 1970s (Barrow, 2016) and expansion of cotton production for foreign markets (Otsyina *et al.,* 1992; Selemani *et al.,* 2012; Barrow, 2014). These programs created severe threats to existing forests and ecosystems-based resources (Barrow, 2016). Further, these programs also abandoned the previous traditional practices, including *Ngitili*, and brought about threats to the ecological system. With the extreme land degradation and deforestation, the region was badly turned into treeless. The late President Nyerere was shocked by what he observed during his visit to the area in 1984. He thereby declared the area as "The Desert of Tanzania" (UNDP, 2012; Barrow, 2016). In response to this calamity, in 1986, the government initiated the land rehabilitation project called the Shinyanga Soil Conservation Programme, better known by its "Swahili acronym HASHI *(Hifadhi Ardhi Shinyanga*), (UNDP, 2012). The primary function is to promote sound land-use technologies' adoption through awareness-raising with tree planting from hand-outs of exotic tree species seedlings from central nurseries on severely degraded land (Selemani *et al.,* 2012; Barrow, 2016). This approach failed because of the harsh weather, termite attack, low acceptance by the community, and poor management (UNDP, 2012).

Observing the failure in the establishment of the HASHI program in the region, project members made a self-reflection and reformation to involve the community (UNDP, 2012) by making people feel that they are responsible for both destruction and restoration of the landscape (Barrow *et al.,* 2002; Minja and Machanya, 2010). Adopting local and traditional knowledge as one of the strategies for forest restoration was thought and taken in place (Otsyina *et al.,* 2008; UNDP, 2012). Thus, the revival and use of indigenous knowledge, attitudes, and practices, such as *Ngitili,* based on indigenous knowledge, were given more priority and became more applicable (Akida and Blomley, 2006; Burgess *et al*., 2010). Local communities were encouraged to participate in forest management by setting aside forest areas to be sustainably managed. Thus, different environmental policies were associated with the system. For instance, Tanzania introduced so-called participatory forest management (PFM), joint forest management (JFM), and Wildlife Management program (URT, 2006; Zahabu *et al.,* 2009; Treue *et al.,* 2014). Other related laws and policies such as; the Village Land Act of 1999 and Land Act of 1999, Tanzania Wildlife Policy of 1998 (Akida and Blomley, 2006), the National Environmental Policy of 1997, the Environmental Management Act of 2004, Forest Act 2002, and its regulations of 2004 (URT, 2006) were also enacted. All of these policies and regulations promoted participatory forest resource conservation and management for sustainable use.

Furthermore, the government recognized the decentralization of power to the local community and the traditional guard (Kamwenda, 2002; Monela *et al.*, 2005; Duguma *et al.*, 2013). The Council of Elders, locally known as "*Dagashida,*" is involved in decision-making to ensure sustainable use of the resources and the welfare of the people in *Ngitili* (Monela *et al*., 2005). At the same time, the traditional guard (police) locally known as *Sungusungu* were given power and became the implementers of the by-laws and protecting the communities against invaders. Heavy fines (e.g., a live cow or 40,000 Tanzanian shillings, approximately to 20 USD) were paid by those who break the by-laws (Minja and Machanya, 2010; Duguma *et al.*, 2013). Different kind of *Ngitili* ownership exists, communal ownership, private ownership (individual ownership, household, and group ownership) and institutional ownership (school and religious organizations), (Kitalyi and Mlenge, 2004; Selemani *et al.*, 2013).

The strong commitment by the local communities and the government attracted attention to the different organizations both within and outside (international, government and privates) that worked under the umbrella of traditional knowledge for land and forest restoration (Nyadzi *et al.*, 2003). For instance, the Norwegian Agency for Development Cooperation (NORAD) became the primary donor of the program to promote *Ngitili* in Shinyanga from 1989 to 2004 (Duguma *et al*., 2019). The International Centre for Research in Agroforestry (ICRAF) has developed and implemented agroforestry practices complementary to *Ngitili* since 2002 (Duguma *et al.*, 2013). The Tanzania Natural Forest Resources and Agroforestry Management Centre (NAFRAC), that takes responsibility of NORAD (UNDP, 2012), the Tanzania Traditional Energy Development and Environmental Organization (TaTEDO) that promotes energy-efficient technologies to reduce GHG emissions, from 2010 to 2013 (TaTEDO, 2009; TaTEDO, 2012). The Development Associates Ltd (DASS) conducts carbon monitoring and accounting in *Ngitili* systems. The programs resulted in outstanding successes. In 2004 more than 152 different trees, shrubs, and herbaceous were recorded in the region (Monela *et al.*, 2005; Selemani *et al.*, 2013). Plant species diversity values ranged from 2.0 to 3.8 concerning Shannon's index (Monela *et al.*, 2005, Zahabu, 2008). A variable range of standing density and tree standing volume was from 922 to 6553 stem ha^{-1} and 5.1 to 48.9 $m^3 ha^{-1}$, respectively (Monela *et al*., 2005; Otsyina *et al*., 2008).

Ceasing of the donors (NORAD) in 2004, most of the programs in *Ngitili* ceased as well (Chirwa, 2014). More ever, the entire situation about the current status of *Ngitili* in terms of conservation, plant diversity, and stocking potentials remains unreported. A few available pieces of works of literature focus on the performances of the pre-existing *Ngitili* and highlight the challenges. For instance, Chirwa (2014) reported that; conflict of interests, ineffective improvement strategies, and lack of recognition of the local institutions and their arrangements had converted the *Ngitili* into other land use. Similarly, Pye-Smith (2010) highlighted the lack of financial incentives and technical support provided by NORAD had accelerated the convention of *Ngitili* to other land use.

On the other hand, agroforestry, which mostly uses alien plant species due to their fast-growing ability, is not palatable to livestock and is characterized by high soil-water consumption (Cazzolla -Gatti *et al.*, 2014). Other noted factors include negative impacts of climate change, natural disturbance, high grazing pressure, bush fires, extensive wood collection, human population, and land competition for human settlement and agriculture (Pye-Smith, 2010; Chirwa, 2014). For instance, poor land preparation practices further threaten the sustainability of *Ngitili* conservation systems, the traditional 'slash and burn', and its typical shifting cultivation. Thus, most of the areas that were used to be *Ngitili* are no longer the same in the Shinyanga region. Unfortunately, the detailed information about these traditional practices (*Ngitili*) on forest management, sustainability, and conservation are highly neglected in the literature. Therefore, we carried out a detailed ecological study in Kishapu district of Shinyanga, northwest Tanzania in order: (i) to assess and document the current status of *Ngitili*, (ii) to determine the diversity of plant species, (iii) to evaluate the regeneration potential of plant species, and (iv) to quantify biomass stocking potential within *Ngitili.*

Description of the study area

The study was conducted in Kishapu district located in the northeast of the administrative region of Shinyanga (Figure 1). The district lies between 3° 15'' and 4° 05'' south of the equator and longitudes 31° 30''E and 34°15'' E east of the Greenwich meridian (URT, 2009). The district has a total area of 4,333 sq. km. About 101 sq. km area is covered by forests, of which 47 sq km is occupied by community conserved forests (*Ngitili)*. The district is characterized by a dry tropical climate with temperatures ranging from 22⁰C to 30⁰C and 15⁰C to 18.3⁰C for maximum and minimum. A semi-arid area receives 450 mm to 990 mm of rainfall per annum (NBS, 2012). Precipitation starts in late October/early November and ends in April/May, while the dry season begins in June and lasts in October. The rainfall amount and distribution patterns are neither even nor expectable (Bushesha and Katunzi, 2017); there is a decrease in rainfall, experiencing a gap between January and February.

The district is characterized by flat and gently undulating plains covered with low and sparse vegetation; soil varies with relief features (KDP, 2013). People in the district are engaging themselves in crops and livestock production. The principal food crops grown include maize, sorghum, bulrush millets, sweet potatoes, paddy, and pulses, while the cash crop is cotton (Katunzi *et al.*, 2016). Livestock kept are cattle, shoats (sheep and goats), and poultry, but fishing is done during the rainy season (KDP, 2013).

Forest inventory design and field layout

Ten (10) community conserved forests, namely, Ikonda A, Mwamanota, Bubinza, Shagihilu, Busongo, Mihama, Bulima, Lyabujije, Ndoleleji, and Nyasamba found in the Kishapu district were selected for the purpose of study. For studying the current status and ecological attributes of Ngitili, ground-based forest inventory techniques (Brand *et al.*, 1991) were employed. Permanent circular plots of 15 m radius (with inner sub-plots of 5 and 10 m) were systematically laid along transects (Zahabu, 2008). The inter

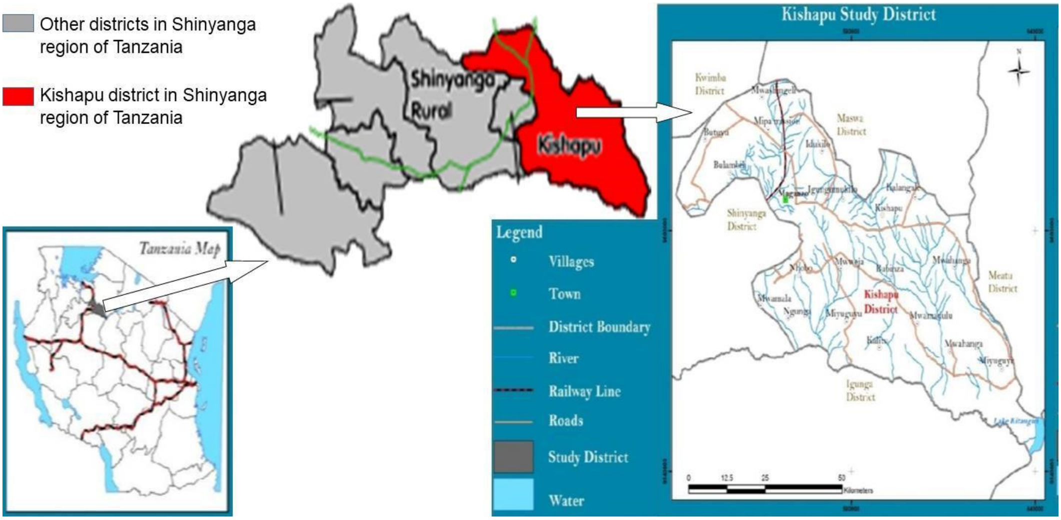

Figure 1. The Map of Shinyanga region to show studied community forests in Kishapu districts, northwest Tanzania.

plots and inter transects distances were maintained at 300 and 600 m, in between, respectively. In each plot, plant phytosociological attributes (number of individual species, frequency, height and diameter at breast height) were recorded in the following manner:

- Within a 5 m radius: the frequencies of the individual herbaceous species were recorded. Seedling (≤ 20 cm height) and saplings (>20 cm, but < 1 m height) were identified and recorded (Rubanza *et al*., 2006).
- Within a 10 m radius: all standing woody plant species with a diameter at breast height (dbh) < 5 cm were identified and recorded as shrubs.
- Within a 15 m radius: all plants with dbh ≥ 5 cm were identified and recorded as trees. In the forked trees, stems were numbered differently, and each stem were measured for dbh at 1.37 m and height. The measuring caliper was used to determine tree dbh (cm), while Suunto clinometer (PM-5/360 PC) was used to determine the tree heights (m) (Modified from Zahabu, 2008).

Data collection

Status of community reserved forests

A field survey was conducted to record the current status of community conserved forests (*Ngitili*). The disturbance score was calculated as per Veblen *et al*. (1992) and Gillespie *et al.* (2000). The disturbance was qualitatively classified into four classes versus the degree of anthropogenic activities (i.e., grazing pressure, wood fuel collection, agriculture, charcoal making, and fire outbreak). The anthropogenic activities were ranked as (1) for no evidence of anthropogenic activity; (2) for one or only two anthropogenic activities evidence; (3) for three shreds of evidence of anthropogenic activities; and (4) for more than three evidence of anthropogenic activities. The sum of all ranks provided the overall ranking of the anthropogenic disturbances (i.e., the low grade represents a low level of disturbance and vice versa). The disturbance index (DI) was calculated based on the number of individual cut stumps observed and recorded in the study site (Kanzaki and Yoda, 1986).

Determination of floristic composition and ecological attributes

The phytosociological study was carried out to recognize vegetation composition and plant species diversity using point sampling methods (Rubanza *et al.*, 2006; Zahabu, 2008). The important plant community attributes such as frequency and abundance were quantitatively computed following Curtis and McIntosh (1950) and basal area following Phillips (1959). The relative frequencies, relative density, and relative dominance were calculated as per Curtis and McIntosh (Curtis and McIntosh, 1950), while the importance value index (IVI) of the individual plant species were determined by summing up the relative frequency, relative density, and relative dominance (Misra, 1989). Plant species diversity, richness, and evenness were computed using indices of diversity as per Shannon and Weaver (1949); Simpson (1949) and Pielou (1966), for Shannon's diversity index (H'), Simpson's dominance index (C), and Evenness index (J'), respectively.

Determination of plant regeneration potential

The regeneration status of plant species was determined based on the population size of seedlings, saplings and adults (modified from (Khumbongmayum *et al.*, 2006). Regeneration status was considered '*good*' regeneration, if seedling > sapling > adults; '*fair*' regeneration, if seedlings > or < saplings <adults; and '*poor*' regeneration, if the species survives only in sapling stage, but no seedling (saplings may be <, > or = adults), (Khumbongmayum *et al.*, 2006). While, if the species is recorded only in adult form, it was considered 'not regenerating', similar species with individuals only in seedlings or saplings without any adult was considered '*newly regenerating*' species.

Plant biomass stocking potential

Herbaceous biomass was determined by the harvest method (Chambers, 1983), a destructive technique that involves clipping off the herbaceous species in a thrown quadrat (Rubanza *et al.*, 2006). The clipped herbaceous species were immediately transferred to pre-weighed labeled bags, and instantly fresh weighted was recorded. The samples were taken into the laboratory for a forced-air oven at 60°C for 48 hours to obtain dry matter (DM). The dry matter contents were used to estimate the biomass production (Chambers, 1983) Eq 1.

$$(1)\ B\ (t\ DM\ ha^{-1}) = \frac{TDM}{TQs} \times QA$$

where; B- biomass, TDM- total dry matter contents, TQs- total quadrats, QA- quadrat area.

While, tree biomass stock was estimated by a non-destructive method (Chave *et al.*, 2014; Chave *et al.*, 2005). The method employs allometric equations, which considers measurable parameters like dbh, tree height, basal area, and wood density (Nath *et al*., 2019): Eqs. 2-4. Above-ground tree biomass (AGB) was computed as per (Vesa *et al*., 2010) Eq 2.

$$(1)\ \text{AGB (kg tree}^{-1}) = \frac{g^{*}\ h^{*}\ \delta}{1000}$$

Where; g- basal area (m^2), h- height (m), δ- wood density.
The BGB was estimated by multiplying the AGB to 0.26 (root to shoot ratio) as per Sheikh *et al*. (2011) and Suryawanshi *et al*. (2014): Eq 3.

$$(3)\ \text{BGB (kg tree}^{-1}) = \text{AGB}^{*}0.26$$

The total tree biomass (TB) was determined as the sum of the AGB and BGB: Eq 4.

$$(4)\ \text{TB (kg tree}^{-1}) = \text{ABG} + \text{BGB}$$

Statistical analysis

All data were normalized to fit parametric tests. Normality and homogeneity were verified using the Shapiro-Wilk and Levene tests, respectively. Descriptive statistics on plant species biomass stocking potential were analyzed statistically using analysis of variance (ANOVA). Fisher's Least Significant Difference Test (LSD) was carried out to test whether the differences between means were statistically significant at $p < 0.05$. All statistical analysis was performed using the SPSS Software package (ver. 20.0; SPSS, Chicago, IL) at a significance level of $\alpha = 0.05$.

Status of community conserved forests

Different forms of fragmentation and the nature of community conserved forests have been observed in the present study. The results on the current status of community conserved forests of the Kishapu district are presented in Table 1. The present study surveyed to record the status in ten (10) community conserved forests in the district covering 6,112.98 ha. Nine conserved community forests contributed 4569.34 ha, while one forest recorded 1543.64 ha converted into other land use. Furthermore, out of the nine community conserved forests, four (2750.13 ha) are threatened (40 %) and turning into a desert-like appearance (Figure 2), while the remaining (five) are highly disturbed (51 %).
The present study observed various ongoing human activities such as forest encroachment, agriculture, and other forms of human-induced disturbances such as burning, overgrazing, fuelwood extraction, which might be attributed to the degradation of the study sites. The factors such as conflict of interest and ineffective improvement strategies could have attributed as well. Other factors include introducing agroforestry, which mainly uses alien plant species due to their fast-growing nature, but in contrast, they require extra care, not palatable by livestock, and fail to adapt to harsh conditions. The reduced powers of the *Dagashida* (Group of elders) and the *Sungusungu* have been deliberated to the disappearance of most community forests.

Table 1. Status of the community conserved forests of Kishapu district, northwest Tanzania.

Name of *Ngitili*	Village (s)	Size (ha)	Factors of disturbance					Measurement of disturbance		
			Graz-ing	Char-coal	Agricul-ture	Wood fuel	Fire	Disturb-ance score	DI	Status
Ikonda A	Ikonda	55	3	1	1	1	1	7	5.51	D
Mwamanota	Mwamanota	100.13	4	3	1	4	1	13	9.47	T
Bubinza	Bubinza	385	2	2	1	2	1	8	5.95	D
Shagihilu	Shagihilu	1168	2	2	2	2	1	9	4.59	D
Busongo	Busongo	475	3	2	2	4	2	13	6.49	T
Mihama	Mihama	500	4	2	2	3	2	13	9.19	T
Bulima	Bulima	1675	4	4	2	3	2	15	12.17	T
Lyabujije	Ng'wani-ma	1543.6	4	4	4	4	4	20	35.1	N
Ndoleleji	Ndoleleji	345	3	1	1	2	1	8	5.76	D
Nyasamba	Nyasamba	190.3	3	2	2	2	1	10	5.68	D
	Total	6437.1								

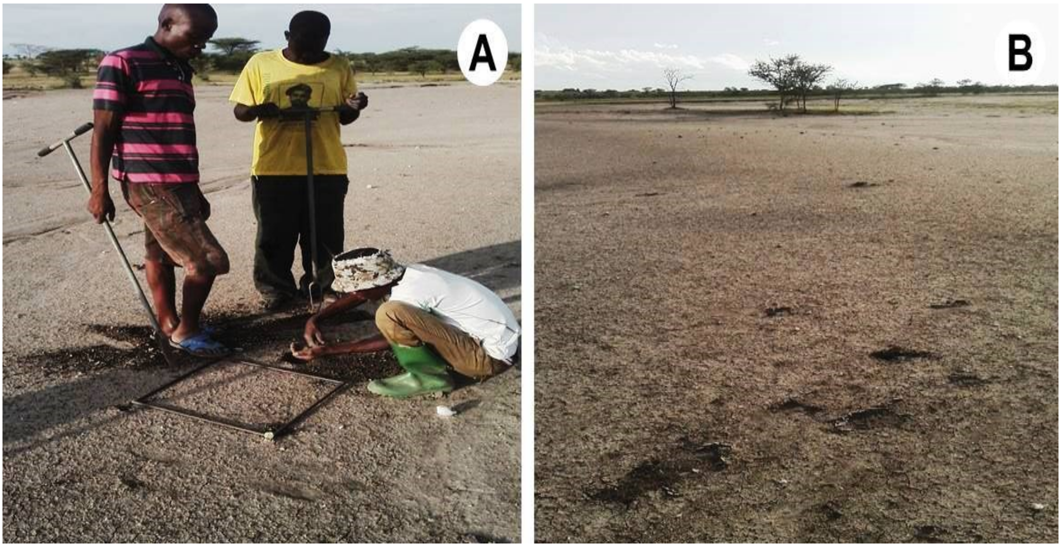

Figure 2. Threatened *Ngitili* showing bare ground with no grass covers turning into a desert-like appearance in Bubinza (A) and Shagihilu (B) community forests Kishapu, Tanzania.

The high level of civilization and the human population has resulted in a great conflict of interest, forcing people to opt for private forest conservation instead of community consideration. Minja and Machanya (2010) reported the exact reasons for declining community conserved forests in Tanzania. Cases related to misuse of forest-related resources are now handled by government police, who usually discourage the action that was taken by the local police *Sungusungu*. Therefore, the unrecognition of the *Sungusungu* in implementing the by-laws and protecting the communities against invaders has increased over exploitation of forest.

The demand for land for human settlement, agriculture, and livestock stocking was attributed significantly to high degradation in the region. Chirwa (2014) reported that much dependence on forest goods and services due to poverty has resulted in forest degradation. Similarly, the ceasing of supports from agents such as NORAD, charcoal making to sustain a livelihood, climate change, natural disturbance, grazing pressure, improper cultivation practices, deforestation, fires outbreak, and extensive fuelwood collection are some of the reasons for degradation in the region (Kamwenda, 2002; Rubanza *et al.*, 2008; UNDP, 2012; Malunguja *et al.*, 2020). On the other hand, Pye-Smith (2010) reported information on the human population and its threat to the community forest ecosystem. According to the report given by the World Agroforestry Centre (ICRAF) (Selemani *et al*., 2012), the growth of urban demand for charcoal and shift from previously practiced communal to private *Ngitili* has augmented the degradation of community conserved forests in the region. The reasons for such movement include low economic return, mainly due to unequal sharing of benefits, poor land security, poor grazing management, and unavoidable conflicts (Adams *et al*., 2003). Village government leaders make the decisions in communal forests on behalf of community members compared to private *Ngitili* (Machanya *et al*., 2003; Treue *et al*., 2014).

Floristic composition and ecological attributes

Herbaceous composition

38 herbaceous species (37 genera and 14 families) were identified in the studied *Ngitili* of Kishapu district in the Shinyanga region (Table 2). 20 species (19 genera and 3 families) were grasses, and 18 species (18 genera and 11 families) were forb and climber species. The dominant grass species include *Aristida* spp. (28.93%), and *Cynodon* spp. (12.9%). Other grass species with relatively high frequencies were *Dactylectenium giganteum* (6.1%) and *Eragrostis curvula* (4.2%), while dominant forb species were *Monechma debile* (4.6%), *Commelina* spp., and *Leucas* spp. Grass species were more diverse (58%) than forb species (42%) in the study sites. The reported dominant herbaceous species in the current study denote that the species are native to the disturbed ecosystem. Grass species such as *Aristida* spp. and *Cenchrus* spp. are good indicators of disturbed aridity and semi-aridity zones (Monela *et al*., 2005; Otsyina *et al*., 2008; Selemani *et al*., 2012). However, the findings from the current work observed few species compared to Monela *et al.* (2005) in the surveyed *Ngitili* forests of Shinyanga. Heavy grazing pressure could have resulted in the disappearance of some native herbaceous species and leads to the domination of the recorded species due to their great tolerate and regeneration potential under harsh conditions. Rubanza *et al.* (2008) reported the decline of some edible herbage species "*decreasers*" as well as the emergence of less nutritious unpalatable species "*increasers*" that tend to dominate the place. The study observed that variation of soils is attributed to the presence of a particular dominant grass species. For instance, species such as *Sorghum* spp., *Digitaria* spp., and *Rhynchelytrum* spp. were found dominant in black clay soil locally known as *Mbuga*. Other grass species such as *Aristida* spp., *Cenchrus* spp., *Heteropogon* spp., *Chloris* spp., and *Branchiaria* spp. were localized in clay loam soil locally known as *Ibushi*. Water-loving species like *Cynodon dactylon* were found dominant in heavy clay vertisol soils (black cotton soil) characterized by high holding capacity and the associated waterlogging, which favors water-loving grass species. The dominant forb species include *Cassia occidentalis, Convolvulus* spp., *Indigofera* spp., *Oxygonum sinuatum,* and *Sida* spp., which indicates disturbed soil characteristics and could be associated with certain forms of land degradation. Pratt and Gwyne (1971) reported the same species in the semi-arid and disturbed landscapes of East Africa. High anthropogenic pressure and the absence of incentive from the government have contributed significantly to the present situation of degraded habitat.

Tree species composition

The present study recorded 28 tree species belonging to 17 genera and 13 families (Table 3). The dominant tree species recorded in the present study is from the genus *Acacia*. Another genus with relatively high dominance in the survey includes *Dichrostachys, Lannea,* and *Balanites*. The study recorded dominant tree and shrub species such as *Acacia. nilotica, A. tortilis., A. drepanolobium., A. delile.,*

Table 2. Herbaceous composition in community forests of Kishapu district, northwest Tanzania.

Botanical name	**Family**	**Composition (%)**
Grass species		
Aristida funiculata Trin. & Rupr	Poaceae	28.9
Branchiaria mutica (Forssk.) Stapf	Poaceae	2.1
Cenchrus ciliaris L.	Poaceae	3.2
Chloris barbata Sw.	Poaceae	1.5
Chloris gayana Kunth	Poaceae	0.6
Cynodon dactylon (L.) Pers.	Poaceae	12.9
Cyperus esculentus L.	Cyperaceae	2.7
Dactyloctenium aegyptium (L.) Willd.	Poaceae	6.1
Digitaria scalarum (Schweinf.) Chiov.	Poaceae	0.8
Echinochloa colona (L.) Link	Poaceae	0.1
Eragrostis curvula (Schrad.) Nees	Poaceae	4.2
Heteropogon contortus (L.) P.Beauv	Poaceae	0.4
Urochloa panicoides P.Beauv.	Poaceae	0.2
Panicum trichocladum Hack. ex K. Schum.	Poaceae	0.7
Rhynchelytrum repens (Willd.) C.E.Hubb.	Poaceae	1.7
Rottboellia exaltata L. f.	Poaceae	0.3
Setaria verticillata (L.) P.Beauv.	Poaceae	1.4
Sorghum bicolor (L.) Moench	Poaceae	0.2
Sporoborus spicatus Kunth	Poaceae	1.8
Themada quadrivalvis (L.) Kuntze	Poaceae	0.9
Forb and climber		
Monechma debile (Forssk.) Nees	Acanthaceae	4.6
Leucas martinicensis (Jacq.) R.Br.	Lamiaceae	3.5
Commelina benghalensis L.	Commelinaceae	3.3
Ipomoea batatas (L.) Lam.	Convolvulaceae	2.8
Tribulus terrestris var. inermis	Zygophyllacea	2.3
Amaranthus spinosus L.	Amaranthaceae	2.2
Oxygonum sinuatum (Hochst. & Steud.)	Polygonaceae	2.2
Lycopersicon lycopersicum (L.) H. Karst.	Solanaceae	1.8
Sonchus luxurians (R. E. Fr.) C. Jeffrey	Asteraceae	1.5
Cucumis anguria L.	Cucurbitaceae	1.1
Corchorus capsularis L.	Malvaceae	0.8
Solanum incanum L.	Solanaceae	0.8
Sphaeranthus suaveolens (Forssk.) DC.	Asteraceae	0.7
Abelmoschus esculentus (L.) Moench	Malvaceae	0.5
Cleome gynandra L.	Cleomaceae	0.5
Convolvulus prostratus Forssk.	Convolvulaceae	0.4
Sida spinosa L.	Malvaceae	0.2
Datura stramonium L.	Solanaceae	0.1

A. polyacantha, and *A. Senegal*. Other species such as *Balanites* spp. (desert plum) dominate the study sites. In order of importance value index (IVI), the dominant species under trees are; *Acacia*

Table 3. Tree species composition community forests of Kishapu district, northwest Tanzania.

Botanical name	Family	IVI
Acacia angustissima (Mill.) Kuntze	Fabaceae	6.77
Acacia bethamii Meisn.	Fabaceae	6.09
Acacia concinna (Willd.) DC.	Fabaceae	25.51
Acacia drepanolobium Harms ex Y.Sjöstedt	Fabaceae	45.37
Acacia nilotica (L.) Del.	Fabaceae	6.63
Acacia polyacantha Willd.	Fabaceae	16.99
Acacia seyal Delile	Fabaceae	15.53
Acacia senegal (L.) Willd.	Fabaceae	33.2
Acacia tortilis (Forssk.) Hayne	Fabaceae	6.63
Albizia amara (Roxb.) Boiv.	Fabaceae	1.63
Azadirachta indica A. Juss.	Meliaceae	5.53
Balanites aegyptiaca (L.) Delile	Zygophyllaceae	42.96
Capparis tomentosa Lam.	Capparaceae	0.57
Cassia abbreviata Oliv.	Caesalpiniaceae	1.79
Colotropis procera (Aiton) W.T.Aiton	Apocynaceae,	0.98
Combretum fraxgrans F.Hoffm.	Combretaceae	1.84
Combretum obovatum F.Hoffm.	Combretaceae	2.66
Dichrostachys cinerea Wight et Arn.	Fabaceae	28.38
Diospyros fischeri Gürke	Ebenaceae	2.57
Euphorbia ingens E.Mey. ex Boiss.	Euphorbiaceae	1.43
Euphorbia tirucalli L.	Euphorbiaceae	8.32
Grewia bicolor. Juss	Tiliaceae	2.29
Lannea humilis (Oliv.) Engl.	Anacardiaceae	33.57
Leucaena leucocephala (Lam.) de Wit	Fabaceae	2.07
Ormocarpum kirkii S. Moore	Fabaceae	3.86
Senna siamea (Lam.) de Wit	Fabaceae	1.5
Senna singueana (Delile) Lock	Fabaceae	1.43
Tamarindus indica L.	Fabaceae	5.53

drepanolobium (45.37), *Balanites aegyptiaca* (42.96), and *Acacia tortilis* (33.57), while *Dichrostachys cinerea*, recorded the highest domination for seedling and sapling.

Species diversity

Analysis of variance (ANOVA) indicated that there was no significant difference ($p > 0.05$) in plant species diversity. Diversity (H') in the present study ranges from 1.02 to 2.42. Grass species recorded the highest diversity (H' = 2.34), while the lowest value was observed in tree species (H' = 2.05) (Table 4). The findings from the present study portray relatively low species diversity, characterizing a few species that dominate the study sites. The predominant species of the genus Acacia in the study area reflects an overgrazed and disturbed land, which should perhaps not be expected to demonstrate high species diversity. The present study observed poor vegetation recovery because of over-grazing, which does not offer sufficient vegetation to recover from one season to another.

Rubanza *et al.* (2008) pointed out that individuals of re-occurring species in *Ngitili* get grazed on their sapling stage; thereby, they never attain the adult stage to produce their next generation. *Ngitili* is only protected during the rainy season and grazed during the peak of the dry season when fodder for livestock is scarce. Thus, the low species diversity observed in the present study is associated with this grazing pressure. The findings from the present study show lower values of diversity (H') which contradicts the data reported in different districts of the region (Monela *et al*., 2005; Otsyina *et al*., 2008). Domesticated animals avoid consuming Acacia species due to the presence of thorns; thus, the species is less affected and dominates *Ngitili*.

Moreover, the species have a less valuable market for timber and charcoal production. According to Monela *et al*. (2005), excellent regeneration potential species like *Dichrostachys cinerea* and *Omorcapum trichocarpum* indicate degraded ecosystems. They have great adaptation to arid and semi-arid regions with low annual rainfall (400 to 800 mm). These recorded tree and shrub species have similarly been reported in other parts of the region (Monela *et al*., 2005; Rubanza *et al*., 2006; Otsyina *et al*., 2008; Selemani *et al*., 2013). The high level of forest degradation and deforestation observed in the studied *Ngitili* might have been influenced by fewer plant species. Furthermore, Tefera *et al.* (2007) reported that plant species like Acacia might reflect an overgrazed land.

Table 4. Dominant species, diversity of plant species recorded in community reserved forests of Kishapu district, northwest Tanzania.

Plant category	Dominant plant species based on calculated composition (%) and IVI	SR	H'	C	J'	EF	WI	NF	NG
Grasses	*Aristida* spp. (28.93 %), *Cynodon* spp. (12.9 %), *Dactyloctenium giganteum* (6.1 %), *Eragrostis curvula* (4.2 %) and *Cenchrus ciliaris* (3.20 %).	20	1.02-2.34	0.08-0.11	0.91	9	0.06	3	19
Forbs and climbers	*Monechma debile* (4.6 %), *Leucas martinicensis* (3.5 %), *Commelina benghalensis* (3.3 %), *Ipomoea batatas* (2.8 %) and *Tribulus terrestris* (2.3 %).	18	1.13-2.42	0.09-0.04	0.9	13	0.09	11	18
Trees	*Acacia drepanolobium* (45.37), *Balanites aegyptiaca* (42.96), *Lannea humilis* (33.57), *Acacia tortilis* (33.20) and *Dichrostachys cinerea* (28.38).	28	1.90-2.05	0.07-0.12	0.93	6	0.06	13	17

Note: SR -species richness; H' -Shannon-Wiener diversity index; C -Simpson's index (1/D); J' -Pielou's index of evenness; EF -effective number of species; WI -Whitford index; NF -Number of the family; NG -Number of the genus.

Regeneration potential status

The present study observed a high percentage (51.85 %) of plant species exhibits a "*Not regeneration*" condition followed by "*Poor regeneration*" (25.4 %), "*Fair regeneration*" (20.7 %), and "*Good regeneration*" recorded the lowest value (2.1 %). The present study doesn't observe any newly regenerated species (Table 5). The absence of new regeneration in the study area indicates that the prevailing environmental conditions are either unsuitable for new species to colonize or there is high pressure of grazing and other anthropogenic activities that fail to establish new upcoming species. The present study's findings portray a destructive regeneration potential, an indicator of threat to the native species leading to local extinction. Illegal utilization of species by communities to sustain their livelihood for charcoal making, medicinal, unstable climate, and edaphic variability attributes to poor regeneration of individual species. Both anthropogenic and natural phenomena affect regeneration potential (Iqbal *et al*., 2012). Scarcity of grazing land and lower ecological carrying capacity resulted from poor adaptability of some species to degraded ecosystem contributed to the degradation of plant species among *Ngitili* in Shinyanga (Selemani *et al*., 2012). Therefore, the sustainability of the *Ngitili* is threatened by extensive grazing and overexploitation of species by communities to meet their daily livelihood requirements.

Tree biomass stocking

The total tree stocking is 12. 04 tB ha^{-1} and results of tree biomass stocking potential are presented in Table 7. Plant species that have relatively high stocking potential are; *Acacia polyacantha* (2.11 tB ha^{-1}), *Acacia tortilis* (1.46 tB ha^{-1}) and *Balanites aegyptiaca* (1.33 tB ha^{-1}). The community forests recorded relatively low biomass stocking potential compared to other reports in the region (Zahabu, 2008). The observed low stocking potential signifies the high degree of disturbance, particularly illegal tree cutting for charcoal making. This is evidenced by the presence of charcoal kilns and a large number of cut stumps. Other reasons could be explained by the absence of large-sized tree individuals with sufficient girth and height, which are essential parameters for assessing tree stocking. The present study observed that most large-sized trees are cut for charcoal making to sustain livelihood and family economy. The low biomass in community reserved forests of the region signifies poor carbon dioxide (CO_2) contribution offset through carbon sequestration for enhanced climate change mitigation. The present study recorded a range of 14 to 4454 stems ha^{-1}, an average of 8.12 cm, and 4.67 m for tree diameter at breast height (dbh), and heights (h), respectively. The findings of this study concur with Selemani *et al.* (2013), who reported an average of 578±70 tree stems ha^{-1} and a height of 3.24 m in Shinyanga rural of Meatu districts. However, the findings from the present study are lower than the data reported by Monela *et al*. (2005) of 1964 to 6553 stems ha^{-1}, and 6.7 to 27.2 cm, for tree stem density and diameter at breast height (dbh), respectively. The estimated values are similarly contrasted to Otsyina *et al.* (2008) of 1053 to 1360 stems ha^{-1}. The high level of forest degradation and deforestation observed during the present study is directly related to the low biomass stocking. The growing urban demand for charcoal has accelerated the degradation of *Ngitli*. Furthermore, a great shift from community-owned to private *Ngitili* in the region is among the main reasons for the degradation and low biomass stocking.

Table 5. Tree species composition community forests of Kishapu district, northwest Tanzania.

Botanical name	**Number of individual adult plants**				**Regeneration status**
	Shrubs	**Trees**	**Seedlings**	**Saplings**	
Acacia nilotica (L.) Del.	41	124	38	67	FR
Acacia drepanolobium Harms ex Y.Sjöstedt	135	315	326	432	GR
Acacia angustissima (Mill.) Kuntze	2	2	1	0	NR
Acacia polyacantha Willd.	15	15	3	11	NR
Acacia senegal (L.) Willd.	3	15	4	6	NR
Acacia bethamii Meisn	5	6	0	2	PR
Acacia tortilis (Forssk.) Hayne	28	102	9	16	FR
Azadirachta indica A. Juss.	1	2	1	2	NR
Balanites aegyptiaca (L.) Delile	40	142	21	18	FR
Capparis tomentosa Lam.	44	3	0	3	NR
Cassia abbreviata Oliv.	1	2	0	0	NR
Colotropis procera (Aiton) W.T.Aiton	7	1	13	24	FR
Combretum obovatum F.Hoffm	5	1	0	0	NR
Dichrostachys cinerea Wight et Arn.	95	101	87	65	GR
Euphorbia tirucalli L.	1	2	0	0	NR
Euphorbia ingens E.Mey. ex Boiss.	12	1	7	9	FR
Grewia bicolor. Juss	7	1	2	6	NR
Leucaena leucocephala (Lam.) de Wit	19	6	13	21	FR
Senna siamea (Lam.) de Wit	1	1	17	5	FR
Senna singueana (Delile) Lock	6	1	0	0	NR
Tamarindus indica L.	1	2	0	6	PR
Ormocarpum kirkii S. Moore	21	7	6	19	FR
Acacia concinna (Willd.) DC	81	151	21	43	GR
Combretum fraxgrans F.Hoffm.	14	1	0	0	NR
Diospyros fischeri Gürke	5	6	1	3	NR
Albizia amara (Roxb.) Boiv.	10	1	13	6	FR
Lannea humilis (Oliv.) Engl.	125	2	37	123	GD

Conclusion

From the present study, anthropogenic activities (i.e., cultivation, deforestation, overutilization, overgrazing etc.) attributed to the observed threatened status in community reserved forests (*Ngitili*) of Kishapu district, northwest Tanzania. Lack of incentives regarding awareness, monetary and technical

Table 6. Herbaceous productivity (ANOVA, LSD and descriptive statistics for minimum, maximum, and Mean±SD) in community forests of Kishapu district, northwest Tanzania.

ANOVA				**LSD**					**Descriptive statistics**				
				(I) Herb's category	**(J) Herb's category**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**		**N**	**Min**	**Max**	**Mean ±SD**
	df	***F***	***Sig.***	Grasses	Forbs	-1.46732*	0.35196	0.000	Grasses	120	0.17	3.68	2.31± 0.03
Between Groups	2	168.681	0.000		Climbers	-0.18604*	0.35196	0.000					
Within Groups	357			Forbs	Grasses	2.46732*	0.35196	0.000	Forbs	120	0.15	3.35	0.37± 0.02
Total	359				Climbers	-1.71872*	0.35196	0.000					
				Climbers	Grasses	0.18604*	0.35196	0.000	Climbers	120	0.07	1.63	0.08± 0.06
					Forbs	1.71872*	0.35196	0.000	Total	360	0.07	3.68	1.09± 0.03

* The mean difference is significant at the 0.05 level.

Table 7. Tree-wise biomass stocking potential in community forests of Kishapu district, northwest Tanzania.

Botanical name	**Stems ha^{-1}**	**Height (m)**	**dbh (cm)**	**Volume (m^3 ha^{-1})**	**AGB t ha^{-1}**	**BGB t ha^{-1}**	**TB t ha^{-1}**
Acacia nilotica (L.) Del.	1753	6.8	18.5	1.231	0.616	0.154	0.770
Acacia drepanolobium Harms ex Y.S.	4454	4.4	5.5	0.143	0.071	0.018	0.089
Acacia angustissima (Mill.) Kuntze	28	5.6	10.9	0.897	0.448	0.112	0.560
Acacia polyacantha Willd.	212	7.4	16.8	3.381	1.691	0.423	2.113
Acacia senegal (L.) Willd.	212	4.3	9.5	0.489	0.244	0.061	0.306
Acacia bethamii Meisn	84	5.9	11.3	0.951	0.475	0.119	0.594
Acacia tortilis (Forssk.) Hayne	1442	7.1	15.8	2.331	1.166	0.291	1.457
Azadirachta indica A. Juss.	28	4.6	6.7	0.737	0.368	0.092	0.460
Balanites aegyptiaca (L.) Delile	2007	6.1	8.8	2.122	1.061	0.265	1.326
Capparis tomentosa Lam.	42	2.7	4.7	0.129	0.065	0.016	0.081
Cassia abbreviata Oliv.	28	3.7	6.4	0.171	0.085	0.021	0.107
Colotropis procera (Aiton) W.T.Aiton	14	1.6	3.6	0.038	0.019	0.005	0.024
Combretum obovatum F.Hoffm	14	3.9	4.2	0.299	0.150	0.037	0.187
Dichrostachys cinerea Wight et Arn.	1428	3.6	5.2	0.254	0.127	0.032	0.159
Euphorbia tirucalli L.	28	5.3	7.9	1.317	0.658	0.165	0.823
Euphorbia ingens E.Mey. ex Boiss.	14	4.2	6.2	0.159	0.079	0.020	0.099
Grewia bicolor. Juss	14	3.6	3.4	0.235	0.117	0.029	0.147
Leucaena leucocephala (Lam.) de Wit	84	5.3	5.3	0.152	0.076	0.019	0.095
Senna siamea (Lam.) de Wit	14	5.7	8.7	0.228	0.114	0.029	0.143
Senna singueana (Delile) Lock	14	3.1	5.8	0.118	0.059	0.015	0.074
Tamarindus indica L.	28	6.5	13.6	1.041	0.520	0.130	0.650
Ormocarpum kirkii S. Moore	98	2.8	6.5	0.234	0.117	0.029	0.146
Acacia concinna (Willd.) DC	2135	6.4	8.8	0.673	0.337	0.084	0.421
Combretum fraxgrans F.Hoffm.	14	5.4	5.8	0.275	0.138	0.034	0.172
Diospyros fischeri Gürke	84	3.2	6	0.148	0.074	0.018	0.092
Albizia amara (Roxb.) Boiv.	14	2.6	3.2	1.374	0.687	0.172	0.859
Lannea humilis (Oliv.) Engl.	28	4.3	10.2	0.133	0.066	0.017	0.083
Total	**14323**	**126.10**	**219.30**	**19.26**	**9.63**	**2.41**	**12.04**

support, and unequal sharing of resources from communal-owned *Ngitili* have played a significant role in low plant species diversity among *Ngitili.* Similarly, the Elders' Council reduced authority power, locally known as "*Dagashida,*" and the unrecognition of the local guard (police) known as *Sungusungu* in implementing the by-laws and protecting the communities against invaders has increased forest overexploitation. Low levels of environmental education, poverty, and more demand for land expansion for agriculture due to increasing population have accelerated deforestation and land degradation. On the other hand, the high level of forest degradation and deforestation observed in the present study is directly related to the low plant species diversity, primary biomass production, and stocking. Therefore, effective and appropriate management interventions such as environmental education to raise awareness are of utmost importance. Re-establishment and strengthening community participation in conservation and management practices for sustainable harvest and resource utilization are required with practical action to enhance forests and land sustainability.

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Chapter
[10]

An overview on aquatic biodiversity of India

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Abstract

Globally the actual number of species in world is estimated to be between 10- 30 million species, in which about 2 million species which have been identified. Freshwater ecosystems account for 0.01% of the earth's surface water but 10% of species. According to the UN Environment Programme. The study of biodiversity on both global and regional scales come mainly from the terrestrial environment despite the marked distinctive features of marine biodiversity and the fact that the aquatic (freshwater & marine) environment occupies more than two thirds of the Earth's surface. The highest loss of freshwater biodiversity has been reported from the Indian subcontinent, specifically the Gangetic plains. Reason why the government has taken up the project of biodiversity conservation in the region. Each species is adapted to its unique niche in the environment, from the peaks of mountains to the depths of deep-sea hydrothermal vents, and from polar ice caps to tropical rain forests. Biodiversity is not only the richness of species; it is also their genetic variety and the multiple habitats and ecosystems in which these plants and animals live. Ecosystems contain both the living plants and animals and the nonliving elements (water, sunlight, soils) on which they depend.

Keywords Aquatic, Biodiversity, Diversity, Fauna, Flora, Marine

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Introduction

Aquatic biodiversity can be defined as the variety of life and the ecosystems that make up the fresh water, tidal, and marine regions of the world and their interactions. Biodiversity is the variety of life on Earth, it includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems. Biodiversity is the varied and differences among living organisms of terrestrial, marine and other aquatic ecosystems and the ecological complexes associated with them. It includes genetic diversity within and between species of ecosystems (Jena and Gopalkrishnan, 2012). It encompasses diversity at three levels: Genetic diversity-genetic variability within a species; Species diversity- variety of species within community; Ecosystem diversity-the organization of species in an area into distinctive plant and animal communities. Biodiversity is not only the richness of species, it is also their genetic variety and the multiple habitats and ecosystems in which these plants and animals lives. The study of biodiversity on both global and regional scales come mainly from the terrestrial environment despite the marked distinctive features of marine biodiversity and the fact that the aquatic (freshwater and marine) environment occupies more than two thirds of the Earth's surface. Each species is adopted its unique niche in the environment, from the peak of mountains to depth of deep ocean, and from polar ice caps to tropical rain forest (Tiwari and Bisht, 1991). Aquatic biodiversity is the rich and wonderful variety of plant and animals. It consists of phytoplankton, zooplankton, aquatic plants, insects, fishes, birds, mammals and others. Many species of animals and plants live in water; some, like fish, spend all their live underwater, whereas others, like toads and salamanders, may use surface waters only during the spring breeding season or as juveniles. Some aquatic creatures live their entire lives in the deep ocean, whereas others, like water striders, spend their life skipping along the surface of water (Chandra *et al*. 2017).

Biological biodiversity is the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystem and the ecological complexes. An ecosystem contains both biotic and abiotic components. Aquatic ecosystem includes our rivers and streams, ponds and lakes, oceans and bays, and swamps and marshes and their associates. As with terrestrial ecosystems, aquatic biodiversity varies from region to region. Aquatic biodiversity is greatest in tropical latitudes. About 22000 species of fishes have been recorded in the world; of which, about 11% are found in Indian waters. Out of the 2200 species so far listed, 73 (3.32%) belong to the cold freshwater regime, 544 (24.73%) to the warm fresh waters domain, 143 (6.50%) to the brackish waters and 1440 (65.45%) to the marine ecosystem (Venketraman and Raghunathan, 2015). Adequate protection of ecosystems is a necessary requirement for survival of all species and proper care is needed to overcome anthropogenic stresses. In the case of commercial species, rational exploitation is a pre- requisite for sustainability of the resources. There are about 450 families of freshwater fishes globally. Roughly 40 are represented in India (warm freshwater species). About 25 of these families contain commercially important species. Coral reef habitats also have extremely high biodiversity; nearly a quarter of all known marine species are found in coral reefs. The Great Barrier Reef, off the coast of Australia, is the largest coral reef system in the world. It supports over 700 species of coral, in addition to 1,600 fish species and 4,000 species of mollusks. Over 1.4 million identified species live on earth, and experts estimate that as many as another 10 million to 100 million unidentified species may exist (Joshi *et al*., 2015).

Fresh water biodiversity

Freshwater ecosystems are a subset of Earth's aquatic ecosystems. They include lakes, ponds, rivers, streams, springs, bogs, and wetlands. Limnology (a branch of freshwater biology) is a study about freshwater ecosystems. It is a part of hydrobiology. Freshwater habitats can be classified by different factors, including temperature, light penetration, nutrients, and vegetation (Robert, 2001). Temperature in fresh water habitats does not show much range of variation, due to several unique thermal properties of water. Turbidity of water depends upon the kinds and amount of suspended material like silt, clay particle and living organism etc. Turbidity affects the penetration of light and thus is important factor in the distribution of organisms. Large rivers have comparatively more species than small streams. Many relate this pattern to the greater area and volume of larger systems, as well as an increase in habitat diversity. Some systems, however, show a poor fit between system size and species richness. Organisms in fresh water habitats are generally classified in to following manner: on the bases of their major niches, their life habit and sub habitat they are autotrophs (producers), phagotrophs (macroconsumers), saprotrophs (decomposer or microconsumer), benthos (bottom), periphyton (attached to other plants), planktons (floating), nekton (swimming) and neuston (resting or swimming on surface). Freshwater ecosystems can be divided into lentic ecosystems (still water) and lotic ecosystems (flowing water).

The earliest vertebrates appeared in the form of fish, which live exclusively in water. Tiny fish may be ancestor of nearly all living vertebrates (Live Science, 2014). Some of these evolved into amphibians which spend portions of their lives in water and portions on land. Other fish evolved into land mammals and subsequently returned to the ocean as seals, dolphins or whales. Plant forms such as kelp and algae grow in the water and are the basis for some underwater ecosystems. Plankton and particularly phytoplankton are key primary producers forming the general foundation of the ocean food chain. Fresh-water habitats are threatened by many factors, including pollution from industry, increased acidification, and agricultural runoff containing residues of fertilizers or pesticides. In addition, the building of dams destroys many river ecosystems. Development can harm aquatic habitats or remove them altogether, as when marshy areas are filled. In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done by Chaudhuri along with Hora and his co-workers. Misra (1976) published An Aid to Identification of the Commercial Fishes of India and Pakistan and The Fauna of India and Adjacent Countries. Jones and Kumaran described about 60 species of fishes in the work Fishes of Laccadive Archipelago. The FAO Species Identification Sheets for Fishery Purposes - Western Indian Ocean (Fischer and Bianchi) is still a valuable guide for researchers.

Lentic communities

Lentic communities are found in three distinct zone i.e., littoral, limnetic and profundal. Producers like, rooted and benthic plants (*Nymphaea, Nelumbo*), mainly seed plants, rooted hydrophytes (*Typha, Scirpus, sagittaria, Eleocharis etc*.), floating green plants, the phytoplanktons, mainly the algae are distributed in these zones. These algae are diatoms, green algae, including unicellular forms as desmid, filamentous (attached or floating) as species of *Spirogyra, Oedogonium, Cladophora, Chara etc*., and various colonial forms as *Volvox*, *Hydrodictylon* etc.; blue green algae, which are unicellular and colonial. In littoral zone the consumer is animal in which vertical rather than horizontal zonation is more striking. The zooplankton represents a few species but their number is large. *Copepods, cladocerans* and *rotifer*s are chiefly present. Common forms are other vertebrate taxa inhabit lentic systems as well. These include amphibians *(e.g. salamanders and frogs),* reptiles *(e.g. snakes, turtles, and alligators)*, and a large number of waterfowl species (Moss, 1998). Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above Fish size, mobility, and sensory capabilities allow them to exploit a broad prey base, covering multiple zonation regions. Like invertebrates, fish feeding habits can be categorized into guilds. In the pelagic zone, herbivores graze on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivores include fishes that feed on zooplankton in the water column *(zooplanktivores),* insects at the water's surface, on benthic structures, or in the sediment (insectivores), and those that feed on other fish (*piscivores*). Fish that consume detritus and gain energy by processing its organic material are called *detritivores*. Omnivores ingest a wide variety of prey, encompassing floral, faunal, and detrital material. Finally, members of the parasitic guild acquire nutrition from a host species, usually another fish or large vertebrate (Poff *et al*., 2006). Fish taxa are flexible in their feeding roles, varying their diets with environmental conditions and prey availability. Many species also undergo a diet shift as they develop. Therefore, it is likely that any single fish occupies multiple feeding guilds within its lifetime (Lytle, 1999).

Lotic communities

Lotic systems typically connect to each other, forming a path to the ocean (spring → stream → river → ocean). Up to 90% of invertebrates in some lotic systems are insects. These species exhibit tremendous diversity and can be found occupying almost every available habitat, including the surfaces of stones, deep below the substratum, and in the surface film. Invertebrates are important as both consumers and prey items in lotic systems. Insects have developed several strategies for living in the diverse flows of lotic systems. Some avoid high current areas, inhabiting the substratum or the sheltered side of rock (LeRoy *et al*., 2006). In addition to these behaviors and body shapes, insects have different life history adaptations to cope with the naturally-occurring physical harshness of stream environments (Lytle *et al*., 2004). The common orders of insects that are found in river ecosystems include Ephemeroptera (also known as a mayfly), Trichoptera (also known as a caddisfly), Plecoptera (also known as a stonefly, Diptera (also known as a true fly), some types of Coleoptera (also known as a beetle), Odonata (the group that includes the dragonfly and the damselfly), and some types of Hemiptera (also known as true bugs). Additional invertebrate taxa common to flowing waters include mollusks such as snails, limpets, clams, mussels, as well as crustaceans like crayfish, amphipoda and crabs.

Fish are probably the best-known inhabitants of lotic systems. The ability of a fish species to live in flowing waters depends upon the speed at which it can swim and the duration that its speed can be maintained. Continuous swimming expends a tremendous amount of energy and, therefore, fishes spend only short periods in full current. Instead, individuals remain close to the bottom or the banks, behind obstacles, and sheltered from the current, swimming in the current only to feed or change locations. Some species have adapted to living only on the system bottom, never venturing into the open water flow. These fishes are dorso-ventrally flattened to reduce flow resistance and often have eyes on top of their heads to observe what is happening above them. Some also have sensory barrels positioned under the head to assist in the testing of substratum. Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species, and mammals (e.g., otters, beavers, hippos, and river dolphins). Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species, and mammals (e.g., otters, beavers, hippos, and river dolphins). With the exception of a few species, these vertebrates are not tied to water as fishes are, and spend part of their time in terrestrial habitats (Giller and Malmqvist, 1998). Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Marine diversity

Marine ecosystems, the largest of all ecosystems (The Marine Biome, 2018*).* A large proportion of all life on Earth lives in the ocean. The exact size of this large proportion is unknown, since many ocean species are still to be discovered. The ocean is a complex three-dimensional world covering approximately 71% of the Earth's surface (Marine Conservation Institute, 2013). They are distinguished from freshwater ecosystems by the presence of dissolved compounds, especially salts, in the water. In its simplest form, biodiversity or biological diversity is therefore 'Life on Earth' and includes marine biodiversity 'Life in the Seas and Oceans. The marine environment has a very high biodiversity because 32 out of the 33 described animals phyla are represented in there (MarBEF's, 2009). A greater variety of species at a higher tropic level are exploited in the sea than on land. Marine life, or sea life or ocean life, is the plants, animals and other organisms that live in the salt water of the sea or ocean, or the brackish water of coastal estuaries. At a fundamental level, marine life affects the nature of the planet. Marine organisms produce oxygen. Shorelines are in part shaped and protected by marine life, and some marine organisms even help create new land. Marine diversity totally depends upon the pattern or the relationship between organism and the sea environment. Exploitation of marine biodiversity is also far less managed than on land (Heip *et al*., 1998, Giller *et al*., 2004). Environmental change in the sea has a much lower frequency than on land, both temporally and spatially. Marine organisms play crucial roles in many bio-geochemical processes that sustain the biosphere, and provide a variety of products and functions which are essential to mankind's well-being, including the production of food and natural substances.

Marine systems are more open than terrestrial and dispersal of species may occur over much broader ranges than on land (Heip *et al*.. 1998). The main marine primary producers are very small and often mobile, whereas on land primary producers are large and static. The standing stock of grazers is higher than that of primary producers in the sea, the reverse of the situation on land. In the largest part of the ocean, beneath the shallow surface layers, no photosynthesis occurs at all (Heip *et al*., 1998, Giller *et al*., 2004). In addition, pollution from the air, land and freshwater ultimately enters the sea and therefore marine biodiversity is most exposed to, and critically influences the fate of, pollutants in the world (Heip *et al*., 1998). Marine ecosystems can be divided into many zones depending upon water depth and shoreline features. The shallow water zone on the continental shelf is the Neritic zone, can include estuaries, salt marshes, coral reefs, lagoons and mangrove swamps. The zone between high and low tides is known as the Intertidal zone. The region of the open sea beyond the continental shelf is called Oceanic region, which comprises the region of continental slop and rise- the Bathyal zone; area of the ocean deeps- Abyssal region; and light compensation zone separating an upper thin Euphotic zone from a vastly thicker Aphotic zone (Figure 1) (Kirsten *et al*., 2017).

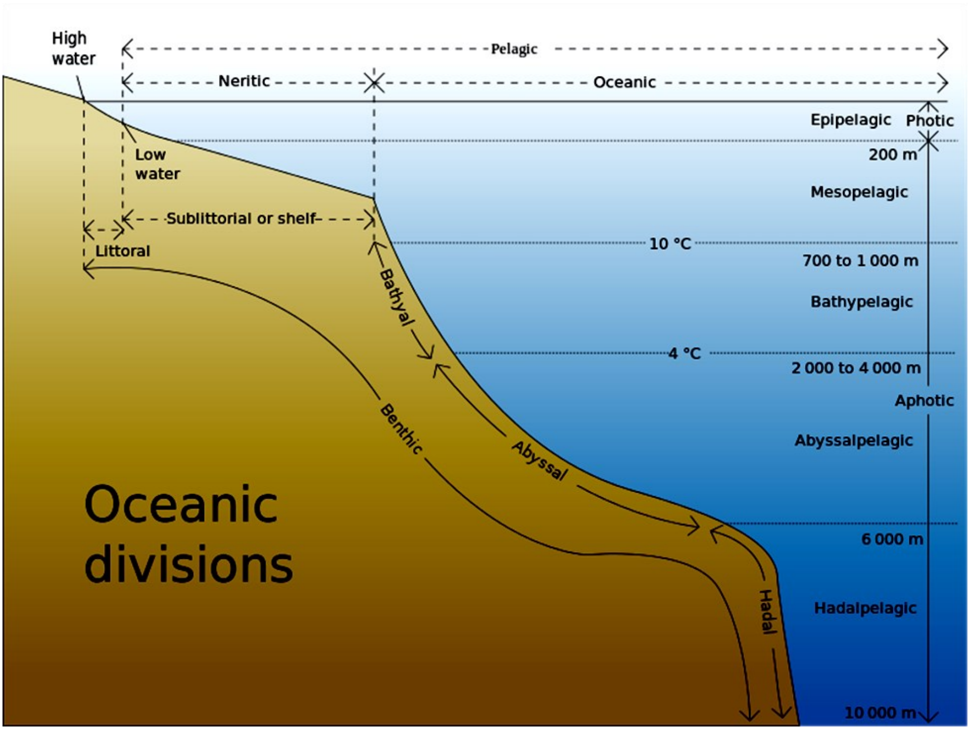

Figure 1. Division of oceanic zones (Adopted from: Kirsten *et al*., 2017).

The organisms of marine environment show great diversity in their form, and it becomes difficult to list. Marine invertebrates are the invertebrates that live in marine habitats. Invertebrate is a blanket term that includes all animals apart from the vertebrate members of the chordate phylum. Invertebrates lack a vertebral column, and some have evolved a shell or a hard exoskeleton. As on land and in the air, marine invertebrates have a large variety of body plans, and have been categorised into over 30 phyla. They make up most of the macroscopic life in the oceans. The earliest animals were marine invertebrates, that is, vertebrates came later. Animals are multicellular eukaryotes and are distinguished from plants, algae, and fungi by lacking cell walls (Davidson *et al*., 2005). Marine invertebrates are animals that inhabit a marine environment apart from the vertebrate members of the chordate phylum; invertebrates lack a vertebral column. Some have evolved a shell or a hard exoskeleton. Invertebrates are grouped into different phyla. Informally phyla can be thought of as a way of grouping organisms according to their body plan (Valentine *et al*., 2004). A body plan refers to a blueprint which describes the shape or morphology of an organism, such as its symmetry, segmentation and the disposition of its appendages. Coelenterates, sponges, echinoderms, annelids e.t.c. that are absent or poorly represented in freshwater are very important in marine water. Insects are generally absent, and the crustaceans constitute the so called "Insect of the sea" (Venkataraman and Raghunathan, 2015). Most life forms evolved initially in marine habitats. By volume, oceans provide about 90 percent of the living space on the planet (Chandra, 2018). Marine invertebrates exhibit a wide range of modifications to survive in poorly oxygenated waters, including breathing tubes as in Mollusca siphons. A reported 33,400 species of fish, including bony and cartilaginous fish, had been described by 2016, more than all other vertebrates combined. About 60% of fish species live in saltwater (Moyle and Leidy, 1992). Fish have gills instead of lungs, although some species of fish, such as the lungfish, have both. Marine mammals, such as dolphins, whales, otters, and seals need to surface periodically to breathe air. A total of 230,000 documented marine species exist, including about 20,000 species of marine fish, with some two million marine species yet to be documented (Bob, 2009). Reptiles which inhabit or frequent the sea include sea turtles, sea snakes, terrapins, the marine iguana, and the saltwater crocodile. Most extant marine reptiles, except for some sea snakes, are oviparous and need to return to land to lay their eggs. Thus most species, excepting sea turtles, spend most of their lives on or near land rather than in the ocean. Despite their marine adaptations, most sea snakes prefer shallow waters nearby land, around islands, especially waters that are somewhat sheltered, as well as near estuaries. (Stidworthy, 1974; Sea snakes at Food and Agriculture Organization of the United Nations, 2007). Some extinct marine reptiles, such as *ichthyosaurs,* evolved to be viviparous and had no requirement to return to land. Marine species range in size from the microscopic, including plankton and phytoplankton which can be as small as 0.02 micrometers, to huge cetaceans (whales, dolphins and porpoises), including the blue whale – the largest known animal reaching up to 33 meters (108 ft) in length (Paul, 2010; Bortolotti, 2008). Marine microorganisms, including bacteria and viruses, constitute about 70% of the total marine biomass, National Oceanic and Atmospheric Administration – Ocean" (NOAA, 2019).

Conclusion and recommendations

India has great diversity in its Geo-climatic conditions. Biodiversity is the varied and differences among living organisms of terrestrial, marine and other aquatic ecosystems and the ecological complexes associated with them. India has great diversity in its geo-climatic conditions. Thus, there is great diversity in India's forest, wetlands, mangroves wildlife and marine areas. The richness in fauna and flora makes it as one of the 12 mega-biodiversity countries of the world. Aquatic ecosystems also are particularly fragile because the disturbance of a watershed can affect multiple components downstream, including rivers, lakes, estuaries, and oceans. Freshwater habitats can be classified by different factors, including temperature, light penetration, nutrients, and vegetation perhaps the largest threat to ocean biodiversity is overfishing. In addition to depleting commercial species of fish, bivalves, and crustaceans, many fishing methods cause the needless deaths of noncommercial fish species as well as numerous reptiles, birds, and marine mammals (Tiwari and Bisht, 1991). The long coastline of 8129 km2 with an EE2 of 2.02 million sq. km including the continental shelf of 0.5 million sq. km harbors extensively rich multitude of species. Vast regions of mangroves are found along the coast of West Bengal, Orissa, Andhra Pradesh, Tamilnadu, Maharashtra, Gujarat and Andaman Islands which extends up to about 6,82,000 ha area. Coral reefs are found in the Gulf of Kutch, along the Maharashtra coast, Kerala coast, in the Gulf of Mannar, Palk Bay and the Wedge Bank along the Tamil Nadu coast and around Andaman and Lakshadweep Islands. The variety of coastal ecosystems includes brackish water lakes, lagoons, estuaries, back waters, salt marshes, rocky bottom, sandy bottom and muddy areas provides a home and shelter for the mega biodiversity of India (Sahil, 2018). These regions support very rich fauna and flora and constitute rich biological diversity of marine ecosystems. Diversity in the species complex, typical of tropical waters and co-existence of different fish and shellfish species in the same ground are important features of Indian Marine Biodiversity (Mishra *et al*., 2017). The diversity in terrain, topography, climate and soils are able to sustain diverse forms of life. Thus, there is great diversity in India's forest, wetlands, mangrove wildlife and marine areas. The richness in fauna and flora makes it as one of the 12 mega-biodiversity countries of the world.

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Chapter
[11]

Avian diversity at Beas River conservation reserve under urbanization and intensive agriculture in Punjab, India

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Abstract

Punjab is an agrarian state nurtured by the river Beas and Satluj with a maximum gross cropped area of 98.5% in India. River Beas had been designated as "Conservation Reserve" in 2017 and "Ramsar site" in 2019. Agriculture affects 87% of the globally threatened bird species. Birds are the most noticeable and specialized species in the river habitats; hence the abundance and distribution of birds are often readily interpreted in the context of river health and vice versa. The chapter has been designed to understand the impact of agriculture, urbanization, tree diversity and wetlands along the river on avian diversity based on literature available for the state of Punjab. The chapter aims to generate sustainable management strategies for the conservation of avian diversity at Beas river conservation reserve without hampering the development of the region. The present work reveals that agriculture intensification and urbanization are major concern for avian diversity conservation as both these factors negatively impacts the habitat specialist bird species and favors generalist and insectivore species. The study concludes that significant number of species recorded have specific niche area requirements that are completed by the river's sub-habitats including feeding, foraging, roosting and nesting therefore the whole area needs protection as a single unit.

Keywords Agriculture, Beas, Birds, Conservation reserve, Punjab, Urbanization

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Introduction

India is a large country blessed with 47 large rivers and hundreds of small tributaries. Indian Rivers consist of Himalayan and peninsular river systems. Himalayan rivers of the country constitute three major river systems i.e., Ganga, Brahmaputra, and Indus. River Beas is an important tributary of Indus River system (Srivastava, 2007) originating in the Shiwalik hill ranges of Himachal Pradesh and feeding a large area of Punjab for its irrigation needs (Moza and Mishra, 2007). Punjab is a small state with a 1.53% area having maximum agricultural intensification with the production of 17 % of wheat, 11 % of rice, and 6 % of cotton in the country (Kaur *et al*., 2018; Gulati and Juneja, 2021). Particularly, Punjab is fed by two major rivers i.e., Beas and Satluj (Grover *et al*., 2017). The irrigation in the state is done majorly by canal systems derived from these rivers. The underground water is another source of irrigation in the state which has decreased drastically due to unsustainable agricultural practices, and has created a cascading effect on the demand for water from canals and rivers (Srivastava *et al*., 2015; Kumar *et al*., 2018). Urbanization and the rapid growth of agriculture during the last few decades have adversely impacted the environment, water quality, and quantity of the flow of rivers (Sharma *et al*., 2017; Pannu, 2018; Rafie and Kumar, 2020). The gross cropped area (GCA) of the state has reached 98.5% (Gulati *et al*., 2021), and there is little scope for the extension of more agricultural area in the state. The quantum of sullage, sewage and agricultural runoff has significantly increased and ran into natural drains, eventually reaching the riverine system of river Beas (Anonymous, 2019).

All these conditions created an inevitable pressure on the natural resources including, rivers and wetlands in the state. The state has only 6.12% of the total area under forest and tree cover accounting for 3,084 sq. km of the state's geographical area. Out of this, only 1181 sq. km area is under reserved and protected categorization. Several studies are available for the avian diversity of Punjab in different habitats, including agriculture (Kler and Kumar, 2015; Kaur *et al*., 2016; Kaur and Kler, 2018; Sethi and Kumar, 2018; Sidhu and Kler, 2018; Kaur and Kler, 2019; Dutta and Dhillon, 2020; Sidhu and Kler, 2021) urban (Kler and Kumar, 2015; Kaur *et al*., 2016; Kaur and Kumar, 2018; Kler *et al*., 2018), natural resources, village pond and wetlands (Brraich *et al*., 2003; Ladhar, 2002; Kler, 2009; Kaur and Kler, 2018; Kler *et al*., 2018; Khalid, 2019; Singh *et al*., 2020; Sidhu *et al*., 2021).

The River Beas provides key habitats for more than 500 bird species and act as a host for summer and winter migratory water birds. The river supports many species of freshwater turtles such as Indian flapshell turtle, Indian softshell turtle, Narrow-headed softshell turtle, Crowned river turtle, Spotted pond turtle, and Brown roofed turtle. Harike and Beas conservation reserve together support more than 90 fish species (RIS, 2020). River Beas was declared a conservation reserve in 2017 under section 36A of the Wildlife Protection Act 1972 by the state government of Punjab (Anonymous, 2019) and designated as the Ramsar site in 2019 (RIS, 2020). The Government of Punjab has made an action plan for conserving the river under the Directorate of Environment and Climate Change, Department of Science, Technology, and Environment (Anonymous, 2019). The action plan emphasizes regulating and cleaning the effluents into the river. River ecosystems are impacted by various stressors that precede a loss of sensitive species and an overall reduction in diversity; therefore, a successful management plan should include the ecological restoration of the habitat. An extensive evaluation of published studies in Punjab and areas near the river Beas were evaluated to generate the habitat management guidelines. Natural conservation of a river is considered much effective if the conservation management efforts are made focusing Hydrology, Biology, Water Quality, and the Morphology of the river (Addy *et al*., 2016). Birds respond very quickly to any alteration in their habitat at any scale. They are also sensitive to disturbances due to human activities as they exhibit specific habitat preferences (Ortega-Álvarez and MacGregor-Fors, 2009). Although a large amount to work is available on avian diversity in different habitats of the state, no conclusive work is available for the faunal diversity of River Beas. The present work has been produced to understand the effect of agriculture and urbanization on ecology of avian diversity in the stretch in Punjab to provide recommendations for the conservation of faunal diversity along the river Beas.

History of River Beas

River Beas is an ancient river with descriptions in Vedas. Vipasa of Mahabharata (Pandey, 2009), Hyphasis of Alexander (Crindle, 1992) were the most commonly known names of this river in ancient India. The river was named Vipas in Rig-veda, which means unfettered. The river was later named as 'Vipasa' in Sanskrit texts (Griffith, 1971). It is believed that the River Beas has been named eponym for rishi Vyasa (author of Indian Epic Mahabharata) (Pandey, 2009). River Beas has been named differently in different periods of time. The other names that were commonly used were Arjikiya (Dey, 1899), Arjikuja (Frowde, 1908), Darya-e-Siyah (Yadgaar, 1985), Beas (Al-Balazari, 1986), Biah (Babur, 1987), Dand Nurni (Fazal, 1988), Ab-i-Siyah (Sirhindi, 1990), Bipasa, Hurhari, Darya-e-Sultan Pur (Ahmad, 1990), Machala (Baqi, 1990) and Darya-e-Gobindwal (Jahangir, 1995). The present name 'Beas' was seen in the imperial gazetteer of India in 1908, describing the tributaries at that time. The chief tributaries are Chakki and Bein. The Chakki collects the drainage of the Chamba hills and joins the Beas near Mirthal, while The Bein formally called Black (Siydh) Bein rises in the Siwaliks, and joins the Beas to miles above its junction with the Sutlej (Forwde, 1908).

The river flowed in its natural phase for millions of years. In the early nineteenth century, plans were initiated to control the flow of this river for irrigation and hydroelectric power generation purposes. Two major dams were built on the river named Pong and Pandoh Dam. The former was completed in 1974 and later in 1977 (Moza and Mishra, 2007). Additionally, the river has rich biodiversity with two main Ramsar sites, i.e., Pong Dam reservoir and Harike wetland. Pong Dam reservoir, also known as Ranjit Sagar Reservoir situated behind the Pong Dam, was constructed in 1975. The reservoir was designated as 'Wetlands of international importance' under the Ramsar Convention in 2002 for its rich diversity. Further, it acts as a temporary shelter for winter migratory birds (Malik and Rai, 2019). The river merges with Satluj at Harike, where another wetland is formed named Harike wetland. This wetland was designated as Ramsar wetland designated in the year 1990 (Mabwoga and Thukral, 2014).

Course of the River

The river originates in Shiwalik hills in the state of Himachal Pradesh and merges with the river Satluj in plains of Punjab state near Harike. River Beas is 460 km long and originates from two primary sources, Beas Rishi on the right of Rohtang Pass at an elevation of 4350 m and Beas Kund at an elevation of 4060 m on the South having a caveran within North-Western Himalaya. Both the streams merge at village Palchan near Manali to give the first appearance of river Beas. The approximate length of the river is 256 km in Himachal Pradesh (HP) and 214 km in Punjab. The total catchment area of the river is 38030 km^2, where 12130 km^2 is spread within Himachal Pradesh and 25900 km^2 Punjab (Moza and Mishra, 2007; Kamboj *et al*., 2021).

Headwaters of the river are steep and, leading 120 km stretch of river with an average fall of 1 in 40. It decreases downstream to 1 in 500 in Beas Valley. The main tributaries of Beas are Parbati, Spin, Malana Nala in the east and Solang, Manalsu, Sujion, Phojal, Sarvati in the west. The river joins Tirthan, Hansa, Bakhli, Jiuni, Suketi, Panddi, Son and Bather from Northside near district Mandi of Himachal Pradesh. Further the river flows toward district Kangra, fed by Banganga, Binwa, Chakki, Dehr, Gej, Neugal from North, and Kunah, Khairan, Maseh, Man from South. The eastern and northern tributaries of Beas are snowfed, making it a perennial river by drainage from southern slopes of Dhauladhar Mountains. The southern tributaries show fluctuation in the flow because of seasonal rains. The flow of water is maximum during monsoon and minimum in winter. In the last decades, the water quantity has been decreased (Moza and Mishra, 2007). The first major anthropogenic manipulation on the course of river is made at village Pandoh in Mandi, where an earth cum rockfill dam with 74.37m height named "Pandoh reservoir" has been constructed (Kumar *et al*., 2007). The reservoir provides 1.58 million cusecs of water, and simultaneously, 4716 cumecs of water are diverted to river Sutlej through the Beas-Sutlej Link canal. The water is diverted via 12.38 km long, 8.15 m. wide tunnel and 11.8 km long lined canal. Another major earth cum rock fill reservoir and dam has been constructed near village Pong in Kangra district to form Pong reservoir, also known as Ranjit Sagar Reservoir. The water spread area is 6000- 24000 ha. The water in the reservoir is utilized for multipurpose activity, mainly irrigation and power generation (Moza and Mishra, 2007).

The river enters the plains of Punjab after leaving Pong dam via Barrage at Talwara (Distt. Hoshiarpur); a large chunk of water is diverted at barrage for irrigation through Shah Nehar Canal. The canal grabs 4170-8611 cusecs of water depending upon the season results in a wide variation in water released in the river ranging from 4.53-68840 cusecs. The river took a loop-like course and traversing through foothills of the Himachal-Nurpur area and gains some water from the Ravi-Beas Link canal made originating from Modhoptar and Chakki near Mirthal. In the way, another tributary named Sarri joins at village Vhed Pattan. The river regains its resources fully through re-induction of Shah Nehar canal near village Terrikein (Distt. Hoshiarpur); thereafter river flows unrestricted in the plains of Punjab, running through district Amritsar, Kapurthala and Firozpur for approximately 100 km towards Hari-Ke-Pattan (Harike). The river collects some more water in between from Chakwal Nalla at village Chakwal (Distt. Hoshiarpur) and Kali Bein near its culmination point at Harike (Moza and Mishra, 2007). The river has higher forest cover before it enters Punjab, and after that, the forest cover decreases at a faster rate. The width of riparian zone decreases, and area get dominated by agriculture. The change in habitat along the river led to variation in the river's diversity (Anonymous, 2019; Brar *et al*., 2020).

Water quality of Beas River

During 2014-15 water quality analysis along with heavy metal contamination was done for river Beas at Beas Kund, Kullu, and Pong dam in Himachal Pradesh, where the maximum parameters were found in the acceptable limits during monsoon, winter, and summer seasons; however, Cd and Pb were found to be higher than acceptable limit of WHO (2011) and BIS (2012). In Punjab, agricultural lands usually receive contaminants from different sources characterized by harmful contaminants and constant bio-accumulation. River Beas has shown contamination by metals in the sediments in recent times. Kumar *et al*. (2018) recorded significantly high pollution levels during pre-monsoon and post-monsoon season with an ecological risk factor of 23.8%, due to heavy metals present in the river. Water quality is a big concern for humankind (Brack *et al*., 2017), and water resources are being contaminated by various anthropogenic activities (Alam *et al*., 2009; 2010).

Anthropogenic activities such as agriculture, mining, and industries, produce a large quantity of heavy metals. These heavy metals are released into the aquatic environment, leading to heavy metal contamination causing the negative impact on biogeochemical cycles (Liu *et al*., 2003; Chabukdhara and Nema, 2012). The assembly of these sediments also causes biomagnification via the food chain (Uluturhan and Kucuksezgin, 2007; Yi *et al*., 2011).Increasing population and intense agricultural practices in Punjab put severe pressure on the natural resources. The whole stretch of the river has been designated as a conservation reserve in 2017. Restrictions were imposed as per Wildlife (Protection) Act, 1972 along the whole stretch (Bisht, 1999).

Lower valleys with agricultural land are prone to contamination from various sources. River Beas is no such exception when it enters the plains of Punjab. Recent studies have observed 28.5% metals contamination during the pre-monsoon season, and 42.8% of metals showed moderate to high pollution during post-monsoon and winter. Overall, the ecological risk factors (ERF) resulted in 23.8% metals in the river, posing moderate to high ecological risk (Kumar *et al*., 2020; Kamboj *et al*., 2021). The population of Punjab has increased drastically in the last few decades and is expected to increase exponentially (PSOP, 2011).

The population of major cities around river Beas is also increasing which would negatively impact the biodiversity around the river. Exponential agricultural growth and urban development result in elevated levels of changes in land use, which cause degradation of natural habitats (Foley *et al*., 2005; Hanski, 2005). River ecosystems are fragile and support rich biodiversity. The present water quality status of river Beas is a matter of concern and needs more substantial efforts.

Effect of urbanization on avian diversity along the river

Urbanization negatively affects natural habitats, woodlands, and riparian areas of streams (Keten *et al*., 2020). Saklani *et al*. (2018) have reported that avian diversity decreases as we go close to the areas having dense population. The nearest available study along rive Beas in urban landscape has shown only 17 residential bird species in urban landscape in Kapurthala (Begowal) region (Kler *et al*., 2015). A total of 63 species of migratory species have also been recorded in urban landscape in Punjab region (Kler and Kumar, 2015). Workers have observed that generalist species were more favored in the urban landscape, with two commensal bird species, i.e., Blue Rock Pigeon and House Crow as the most abundant species in the region of Punjab due to easy food availability (Kler *et al*., 2015). Urbanization along the river may favor the generalist and commensal species in the region. Major cities are usually grown around the rivers due to easy accessibility of river serveries such as drinking water, food, and transport (Groffman *et al*., 2003). Siddiqui *et al*. (2019) have reported that the urban sites are dominated by omnivore species, whereas insectivorous species dominate semi-natural, semirural, and rural natural areas. An increase in non-native bird species due to anthropogenic effects (Marzluff, 2001) is also a stumbling block that may alter the already stressed avian diversity of the region.

Electromagnetic Radiations (EMR) are an integral part of Human settlements in the present time. EMR poses significant health hazards to birds and humans. Sparrows, pigeons, parrots, and swans are some of the birds highly affected by these radiations (Surendran *et al*., 2020). Maximum EMR (Electromagnetic radiations) are generated from mobile towers. Various studies has been conducted in India to check the impact of mobile towers on avian diversity (Durgam *et al*., 2017; Kler *et al*., 2018; Kumar and Singh, 2018; Siddiqui *et al*., 2019; Surendran *et al*., 2020). Most of these studies have shown a negative or neutral relation of avian diversity in proximity of mobile towers. Radio frequency waves hurt the regular navigational capacities of birds (Surendran *et al*., 2020). Low avian abundance and breeding success near mobile towers and high voltage power transmission towers have been observed in Punjab might be due to the clandestine effect of electromagnetic radiations along with the other unforeseen factors (Kler *et al*., 2018). However, uncertainty exists in possible biological effects arise from electromagnetic field exposure on birds (Bhattacharya and Roy, 2013). River Beas harbors a rich avian diversity; it also hosts a large number of migratory birds at Harike wetland. Communication towers may negatively impact the richness and abundance of the species, which needs to be addressed in conservation plans.

River resources are being polluted by industrial and domestic pollutants, where exploitation of ecosystem services in river catchments areas is a well-known phenomenon under downstream effects (Maltby and Ormerod, 2011). However, river Beas also faces similar problems at a lower scale (Kamboj *et al*., 2021). Among all riverine organisms, birds are most noticeable, with specialized traits to exploit the habitat conditions provided by rivers (Buckton and Ormerod, 2002); hence the effects of environmental changes on the abundance and distribution of river birds are often readily interpreted (Ormerod *et al*., 2000) in context of river health. Conservation of Avian diversity could help to conserve the overall river biodiversity (Vaughan *et al*., 2007). Exotic tree and shrub species in urban habitat affects the natural flora and fauna (Acar *et al*., 2007). Due to lower nest predation and higher food availability, native bird species prefer urban areas dominated by native rather than exotic vegetation (Donnelly and Marzluff, 2004; White *et al*., 2005). The urban population is growing continuously and affecting biodiversity within urban environments (Seto *et al*., 2013). Habitat loss, fragmentation, altered species interactions, biotic homogenization, extinction of native species, and proliferation of alien species are the major impacts of urbanization on biodiversity (Grimm *et al*., 2008; Goddard *et al*., 2010; Keten *et al*., 2020). Avian diversity is often taken as biological indicators for the impacts of urbanization on ecosystems because they are easy to observe, identify, ecology is well known, and respond quickly to changes in habitat structure (Vandewalle *et al*., 2010; Fontana *et al*., 2011; Wenny *et al*., 2011). Rivers and wetlands are vital for urban ecological infrastructure. However, rivers are heavily degraded and altered along with urban cities. This phenomenon is known as urban stream syndrome. This syndrome includes alteration in chemical, physical and biological elements of the river by urban development, pollution, disturbance, and catchment inurement (Paul and Meyer, 2001; Walsh *et al*., 2005). Rivers flowing near urban landscape usually experience altered vegetation structure, loss of riparian forest, and reduced diversity (Urban *et al*., 2006). The area along urban streams is usually considered as natural ecosystems having the potential of a local hotspot. However the potential of urban streams and rivers to act as refuges for urban biodiversity has not been explored widely. Some work has been done to understand the avian diversity along urban streams (Dallimer *et al*., 2012; Suri *et al*., 2017), yet the explanation for the impact of the riparian zone of rivers on the functional configuration of urban bird communities is unknown. Although Punjab has made a roadmap for cleaning the river water (Anonymous, 2019) and protecting the river from 'urban stream syndrome,' the plan has no provision for the conservation of natural habitat to create a healthy ecosystem for avian diversity along the river Beas.

Effect of agriculture on avian diversity of river system

There are various threats to bird diversity, but agriculture alone affects 87% of the globally threatened bird species (Bli, 2008). Punjab is a small state with 1.5% area of the total area of India. Still, it alone contributed 1/3rd and 1/4th of central pool wheat and rice, respectively, as per the economic survey of 2019-20. For this purpose, the state relies on intensive agricultural practices. Prevailing condition are creating encroachment pressure on already stressed and small extents of natural habitats available in the state (Singh *et al*., 2020). A significant course of the river Beas flows through an intensive agricultural region of Punjab. After the adoption of new agriculture technology, including hybrid seeds, chemical fertilizer, and new agriculture practices from the mid-1960s, Punjab has made wonderful progress in the field of agriculture (Sidhu, 2005). In 1974, 73 percent area of Punjab was under agriculture, reaching 95 percent in 1983-85 (Jodhka, 2006). Furthermore, rice production had increased from 920,000 tons in 1970-71 to 13,382,000 tons in 2017-18. The intensification of agriculture has increased water scarcity and pressure on land-use changes in the state (Rafie and Kumar, 2020; Gulati *et al*., 2021). Although agricultural intensification has positive impacts, the natural habitats for specialist bird species have decreased in the region.

The state has used its natural resources at a much higher intensity after the green revolution and tilted towards a monoculture system of wheat-paddy (Grover *et al*., 2017; Gulati *et al*., 2021). A total of 189 species have been observed in the villages and agricultural landscape of Punjab, including 111 residents, 47 resident migrants, and 30 migrants with one species in the vagrant category. The diversity includes one endangered, one vulnerable, and eight near threatened species (Kler and Kumar, 2015). A total of 12 carnivorous bird species have been observed in agricultural and mixed fruit orchard of Punjab (Kaur and Kler, 2019). A mixed fruit tree orchard seems to encourage avian abundance than the mono fruit crops orchard. Tree diversity supports more avian richness and is paramount for avian conservation in the agricultural landscape of Punjab (Sidhu and Kler, 2017). Avian composition and their foraging ecology can be utilized for pest management strategies by identifying the insectivorous species for biological control in agricultural fields (Kler and Parshad, 2012). Habitat preference for some species is directly proportional to feeding, roosting, and nesting material in the area (Sohi *et al*., 2017).

Floodplains of a river are one of the most fragile ecosystems and have attracted humans since the dawn of civilizations. The natural land cover of these floodplains has always got the impact of anthropogenic activities. Flood plains of river Beas have also witnessed such changes. Agriculture and human settlements along the river have recorded a sharp increase in the last few decades. GCA of Punjab state is 98.5% (Gulati *et al*., 2021) which infers that the river Beas has agricultural lands on both sides of the river throughout its length in Punjab. The data of land use and land cover shows that anthropogenic pressure is overtaking the natural processes along the river Beas. The ratio of area under land use and land cover was 86:14 in 1989, which infers that the anthropogenic activities had already overtaken the natural ecosystems in the floodplain of Punjab. The ratio further deteriorated during the next decades to 89:11 and 93:07 for the years 2000 and 2015, respectively (Brar *et al*., 2020). Agricultural intensification is considered as one of the leading causes for widespread farmland biodiversity loss (Stoate *et al*., 2001; Tilman *et al*., 2001; Green *et al*., 2005), including reductions in the abundance and richness of many plants and invertebrate taxa (Sotherton and Self, 2000; Preston *et al*., 2002; Piha *et al*., 2007) and the declines of farmland bird populations (Chamberlain *et al*., 2000; Donald *et al*., 2001; Murphy, 2003; Newton, 2004).

The intensification of agriculture in Punjab has pushed the boundaries of the rivers in the state and has narrowed the riparian zone between the river and agricultural areas (Brar *et al*., 2020). The information of bird communities around crop fields and urban settlements is not entirely understood, as there is a contradiction between the results of various studies. For example, it was observed that crop fields do not show complex and diverse bird communities when compared to cattle grazing lands, this was suggested by Morris (2000), whereas MacGregor-Fors and Schondube (2011) shows that the pattern of bird communities may vary with remaining vegetation and the locality of grazing lands in the nearby landscape. At the same time, it was observed that urbanization might not consistently harm birds compared to the agricultural landscape (Bellocq *et al*., 2008), as some agricultural practices may be more harmful to bird communities than the impact of urban development (Faggi *et al*., 2008). Agricultural land use and landscape structure are the principal components of determining bird assemblage;

however, it is not equally accurate for overall avian density, richness, diversity, or biomass. Although the state has rich avian diversity, many bird species are still habitat specialists and are not found in the agricultural landscape. Therefore, the minimum natural areas available in-state are required to be protected. Agricultural grasslands strongly and positively determined the bird assemblage (Piha *et al*., 2007). Studies have shown that greater avian diversity is observed in the forest than in the paddy field. The number of bird species declines if forested areas are converted to agricultural landscapes (Waltert *et al*., 2004; Azman *et al*., 2011). The commercial plantation system is also booming in Punjab to break the regular wheat-paddy cycle of the agroecosystem (Chauhan *et al*., 2012). Some lands are also getting converted into commercial plantations in Punjab; however, conversion of forest to commercial plantations also led to a decline in bird richness and an increase in the relative abundance of wide-ranging, adaptable species (Aratrakorn *et al*., 2006). Fewer species can be observed in paddy fields because these habitats are structurally simpler and offer fewer feeding niches (Fujioka and Yoshida, 2001). Relatively generalist bird species are common in commercial plantations as they have higher adaptability to unfavorable environmental conditions. Commercial plantations are generally categorized as an unfavorable environment owing to the frequent disturbance caused by humans and the low availability of food sources (Aratrakorn *et al*., 2006). Foraging guilds often respond to environmental conditions differently (Balestrieri *et al*., 2015). A decline in the avian population of long-distance migrant species of insectivore birds has been demonstrated by Vickery *et al.* (2014) and Gregory *et al*. (2007) in commercial plantation zones. Avian foraging guilds are more closely associated with plant diversity for insectivores (Sullivan *et al*., 2007) and frugivores bird species richness (Kissling *et al*., 2007). Fewer bird species have been observed in commercial plantations compared with the secondary forest and agricultural fields, especially paddy fields (Azman *et al*., 2011). Farming and paddy seasons are essential aspects of the abundance and distribution of birds in the area (Kelly *et al*., 2008; Ibáñez *et al*., 2010; Wood *et al*., 2010). Studies have suggested that paddy fields are suitable for water birds and land birds as a place to forage, breed, and shelter (Zou *et al*., 2006; Razafimanjato *et al*., 2007; Takahashi and Ohkawara, 2007; King *et al*., 2010; Wood *et al*., 2010). Flood plains of Punjab along river Beas have also witnessed the anthropogenic intervention in the landscapes of the river led to depleted natural ecosystems and land use patterns. Intensive agriculture and urbanization along the river have recorded a sharp increase in the last few decades. The impact of agriculture intensification along the rivers on avian diversity has not been studied, and literature review has shown that agricultural intensification may negatively impact the habitat specialist bird species in the state. On the other hand, generalist and insectivore species seem to increases in the regions along the river in the agricultural landscape; however, deeper studies would be required to understand the variation in species diversity in regions near rivers.

Effect of trees on avian diversity

It is a well-known fact that the natural habitat harbours healthy avian diversity. However, in the states like Punjab, it is not possible to have large forest ranges. Therefore, one of the best ways to deal with

the problem is tree plantation. Suitable habitats can be provided to the threatened (Delarze and Ciardo, 2002) and common species by increasing the size of plantation in the region (Godreau, 1998; Britt *et al*., 2007); however, some adverse effects are associated with the type of plantation (Castano *et al*., 2019).
Under the various negative implications of intensive agriculture, the state has started diverting towards tree plantation and agroforestry models. Poplar (*Populus deltoides*), Eucalyptus (*Eucalyptus tereticornis*), Dek (*Melia composita* and *M. azedarach*), Leucaena (*Leucaena leucocephala*), Kadam (*Anthocephalus cadamba*), and Teak (*Tectona grandis*) are grown on a commercial scale in Punjab (Chauhan, 2005). Poplar is a non-native tree species adopted at a large scale by the farmers of North India, especially Punjab, for monoculture or agroforestry (Chauhan *et al*., 2009; Rizvi *et al*. 2020). Although non-native tree and grass species have not been associated with increased predation risk for nesting birds, they impose a threat to diversity conservation. Land-cover of poplar plantation was 4% in 2012 of the global forest and is continuously increasing (Pawson *et al*., 2013). Adjoining natural habitats along poplar plantations have several effects, including a decrease in bird species richness in the nearby agricultural lands and riparian forests; therefore, the practice should be avoided in areas of high conservation value (Godreau *et al*., 1999; Archaux and Martin, 2009). The second commercially grown tree species in Punjab is Eucalyptus, which harbor lesser avian diversity (Barlow *et al*., 2007; Proena *et al*., 2010; Calvino-Cancela, 2013; Kaur and Kumar, 2020) as compared to the native plantation. A total of 23 species has been recorded in non-native trees in Punjab. Birds are exclusively sensitive and have very close association with trees. Vegetation cover and foliage height influence avian abundance and diversity. Non-native invasive species block the growth of native flora and ultimately result in the decline of nesting sites for birds (Kaur and Kumar, 2019). Avoiding the removal of undergrowth and low branches of trees can create better foraging and nesting niches for birds (Archaux and Martin, 2009).
Banks of the river are generally covered with grass and native tree species. As River Beas has been declared as a conservation reserve, the riparian area of the river can be used to enhance the avian diversity of the region. Native vegetation along with grasslands can provide suitable habitats for native grassland breeding birds (Kennedy *et al*., 2009), whereas forest specialist species are strongly related to landscape characteristics. Secondary forests are essential for conservation efforts; however under the agricultural pressure closed-canopy plantation may present a viable compromise (Carrara *et al*., 2015). Indigenous trees like Neem (*Azardirachta indica*), Banyan (*Ficus benghalenesis*), Jamun (*Syzygium cumini*), Mulberry (*Morus alba*), Pipal (*Ficus religiosa*), and Sheesham (*Dalbergia sissoo*) harbor a significant avian diversity in Punjab (Kaur and Kumar, 2018) hence can be planted in the riparian zone of the river. At the same time, large monocultures of exotic non-native trees with short rotation times can have negative implications whereas, mixed plantations of native trees can provide similar avian diversity as to native forests of the area (Castano *et al*., 2019); hence, the practice of mixed plantation should be promoted in the adjoining agroforestry areas along the river.

Avian diversity at small ponds and wetlands of state

In Punjab, some documentation has been done on water-dependent birds by various authors (Kler and

Kumar, 2015; Soni *et al*., 2017; Kaur *et al*., 2018; Soni *et al*., 2019; Sidhu *et al*., 2021). The state has many small and large wetlands where Keshopur-Miani Jheel, Chhawarian Bhangar Chhamb, Jastarwal Jheel, Mand Bharthala, and Dholbaha Reservoir are designated as wetlands of state significance. In contrast, Harike, Kanjli, and Ropar wetlands have been designated as wetlands of national importance (Ladhar, 2002). However, there is a lack of information about detailed information and trends of avian diversity along the river Beas. The majority of the work has been done on various aspects of Harike wetland in Punjab (Chopra *et al*., 2001; Jain *et al*., 2008; Sarkar and Jain, 2008; Kaur *et al*., 2014; Brraich and Jangu, 2016; Singh *et al*., 2020). Various studies have shown a decline in the water quantity of rivers, leading to degradation of the habitat and increased anthropogenic activities in the area, including agriculture (Jain *et al*., 2008; Malik and Rai, 2019; Singh *et al*., 2020).

Conservation of biodiversity is essential for the stability of ecosystems. Anthropogenic activities constitute a significant threat to biodiversity these days. It has been observed that with the growing human population, biodiversity is decreasing at a faster rate (Bilgrami, 1995; Cincotta *et al*., 2000; Kremen and Merenlender, 2018). Avian populations play a central role in ecosystem services and ecosystem functioning and provide economic benefits like seed dispersal and pollination. They also play a role in the restoration of distressed ecosystems (Sekercioglu *et al*., 2004). The avian diversity along the rivers is generally got impacted by agricultural intensification and urbanization. Flood plains of river Beas are fertile and best suitable for agriculture that makes the river habitat prone to habitat degradation.

Land use and land cover changes are responsible for the loss of ecosystem services of wetlands worldwide. Anthropogenic activities have severely affected the habitat of the Pong dam wetland posing risks of habitat degradation destruction. In the last decade, the barren area has decreased to half while the agricultural area has increased by 159%. Rapid conversion of scrubland land for agriculture purposes has created severe pressure in wetland existence. Under the various anthropogenic and natural pressures, the survival age of the wetland has been estimated to be about 100 years (Malik and Rai, 2019). The case of Harike wetland on river Beas is almost the same. All these conditions can severely change the avian composition of the region, and many essential bird species could get swept out of the region.

The bird species richness is significantly associated with the percent cover of native habitat; however, fragmentation tolerant bird species remains consistent in the region. Riparian banks of rivers exhibit both high avian species richness and abundance. They may act as migration dispersal corridors on a regional scale (Bolger *et al*., 2001) which might get negatively affected by dams and other flood control measures leading to alter the natural river flow system. Artificial structures like dams regulate the flow of the river and can impact the abundance and richness of birds via changes in habitat parameters, which provided food and shelter to birds near dam areas (Wu *et al*., 2017). Studies have suggested that reservoirs play a vital role as staging and wintering areas for migratory birds, especially waterfowls (Wang *et al*., 2013; Ali *et al*., 2011); however, the extent of the repercussions of dam operations is still not known. Most of the studies are done for studying the avian diversity, richness, and abundance of reservoirs made for the rivers. However, the effect on downstream river flow and its effect on avian diversity still needs to be understood. The formation of ponds along rivers is a natural phenomenon. These ponds can be seasonal and sometimes perennial fed by river water (Williams and Fryirs, 2020; Ren *et al*., 2018). Ponds play a significant role in maintaining rich avian diversity by unique habitat and ecosystem services (Smith *et al*., 2002; Cereghino *et al*., 2014; Sidhu *et al*., 2021). Ponds act as a tiny but complete habitat for various plants, insects, amphibians, fish, reptiles, birds, and mammals (Froneman *et al*., 2001; Fairchild *et al*., 2005; Sidhu *et al*., 2021), where birds play major tertiary roles in the ecological pyramid (Lu *et al*., 2007; Ma *et al*., 2010). Various studies in Punjab on ponds have shown significant avian species richness with water-dependent and terrestrial birds (Kaur *et al*., 2018; Kaur and Kler, 2018; Sidhu *et al*., 2021). The village ponds of Punjab are typically recognized by the presence of agricultural fields, weeds, heaps of cattle dung on the side of the pond, which acts as an abundant source of food supply for highly diverse waders and mud probing bird species. At the same time presence of greater tree diversity and wild vegetation near ponds supports more bird species richness (Mahesh *et al*., 2018; Mishra *et al*., 2019; Soni *et al*., 2019; Sidhu *et al*., 2021), where rich floral diversity plays a significant role in maintaining migratory and wintering waterbirds (MacroMendez *et al*., 2015; Mahesh *et al*., 2018).

Most of the wetlands in the state are lost due to a decrease in the water available in wetlands, including Bhupinder Sagar, Chhangali Chhamb, and Rahon de Chhamb. Reduced water flow, siltation, and encroachment are significant reasons for the degradation and loss of the biological diversity of the wetlands (Ladhar, 2002). Harike wetland that harbors the maximum avian abundance and richness faces the same challenge, and the landscape of the wetland is changing (Singh *et al*., 2020). Ponds and wetlands along the rivers can play a vital role in the conservation of avian diversity. Therefore these areas should also be taken into consideration for conservation reserves. Plantation of native weeds, shrubs, and trees can help in increasing the avian diversity of ponds and wetlands.

Importance of riparian zone of river system

The adjoining area of the river bank and flood plains is typically known as riparian zone of the river. This corridor supports aquatic life and riparian wildlife in a number of ways (Collins *et al*., 2010). In a typical system, riparian zones are generally known as Ecotones between terrestrial and aquatic habitats of a river (Sabo *et al*., 2005). Terrestrial and freshwater habitats are linked via riparian zones through physical and energy fluxes (Burdon and Harding, 2008; Johnson and Hering, 2009). These habitats are sensitive to land-use changes due to the high edge-to-area ratio (Martin *et al*., 2006). Anthropogenic activities continuously create a threat to riparian habitats by casing pollution and progressive encroachment of catchment areas along rivers for human use (Allan, 2004). Birds get ample food from emerging insects and various other sources provided by the river and its riparian area (Nakano and Murakami, 2001; Baxter *et al*., 2005). Various processes directly influence birds in riparian areas; therefore, they are considered valuable indicators of the river ecosystem. Bird surveys are generally more cost-effective than classical biological indicators (Mattsson and Cooper, 2006; Vaughan *et al*., 2007). Francl and Schnell (2002) have observed that birds are more responsive to human disturbances than mammals, fish, and macrobenthos in riparian habitats. Bird species that occupy high trophic levels appeared negatively affected. Their abundance and distribution of avian species at higher trophic levels are negatively affected by urbanization and agricultural development (O'Connor *et al*., 2000; Bryce *et al*., 2002; Lussier *et al*., 2006; Mattsson and Cooper, 2006).

Riparian zones along the irrigation canals have been studies in Punjab along the Sidhawan canal. A significant avian diversity with 37.25% of the bird species falling under scare to the rare category was observed in the zone (Kler, 2009). The riparian zone of the river Beas is much broader and less disturbed than the canal. Therefore, there is a high probability of finding rich avian diversity. Rivers provide complex habitats with distinct resources allowing several species to coexist. The obligate riverine birds are diverse in the world with high topographic variation (Buckton and Ormerod, 2002; Buckton and Ormerod, 2008). River birds potentially suitable indicators of river quality ad they get affected at multiple scales by both aquatic and terrestrial changes along the rivers (Larsen *et al*., 2010). Global environmental changes have affected the Himalayan river systems, including glacial retreat, urban encroachment modification of catchments, and riparian zones (Manel *et al*., 2000). The ecological outcomes of these modifications, including the impact on avian diversity along the rivers, are poorly understood. Several anthropogenic degradation activities have made the river less habitable for avian communities, including agricultural intensification, disturbed hydrology, invasive plants, degraded habitat, alterations of channels, reduced biodiversity; and dams (Sinha *et al*., 2019). Almost all parameters can be seen along the river Beas. Generally, avian abundance is higher on rivers sides (Mason *et al*., 2006; O'Neal Campbell, 2008). Avian abundances along the rivers are positively correlated with vegetation and stream size (Ivicheva *et al*., 2019). Both water birds and terrestrial birds benefit from riparian nutritional pathways along the rivers (Jackson *et al*., 2020). Therefore, habitat monitoring along rivers is crucial for the conservation of avian abundance and diversity.

The riparian area provides a complex and diverse terrestrial habitat with unique vegetation compared to adjoining areas. Therefore these areas generally have distinct avian composition and richness. Various studies have been done to understand the impact of local habitat structures in riparian zones on species diversity (Martin *et al*., 2006; Palmer and Bennett, 2006; Palmer *et al*., 2008; Pennington *et al*., 2008; Berges *et al*., 2010; Bennett *et al*., 2014; Gomez *et al*., 2016; Liang *et al*., 2018). Studies have shown that avian richness is positively related to the width of riparian habitats in where trees usually play an important role (Shirley and Smith, 2005; Hillman *et al*., 2016; Nimmo *et al*., 2016). Complex landscapes in riparian strips attract a higher number of bird species (Woinarski *et al*., 2000; Bennett *et al*., 2014; Berduc *et al*., 2015; Terraube *et al*., 2016), while livestock grazing in the region can negatively impact bird species richness (Jansen and Robertson, 2001; Martin and Possingham, 2005; Nelson *et al*., 2011). The other decisive factor affecting species richness in riparian zones includes climate factors, such as precipitation and temperature (Li *et al*., 2013). Riparian landscapes are beneficial to biodiversity and ecosystem functions in tropical areas (Luke *et al*., 2019). The tree diversity along rivers sides is generally rich with a higher number of old trees. Trees are a vital element of nature and play an essential role in maintaining the balance of nature. They have a long life span and die slowly with time. During their life span, they support many organisms to co-exist and assist in completing the life process. The trees may be alive or dead, but they are defined as habitat trees if they act as a habitat for some or other species. These trees provide ecological niches (microhabitats) such as cavities, large dead branches, epiphytes, sap runs, bark pockets, cracks, or trunk rot. These habitat trees have different names based on their characteristics, i.e., ancient or monumental trees have remarkable age or size, whereas cavity trees host cavity-nesting species such as woodpeckers. Habitat trees primarily host avian biodiversity and harbor many endangered species of birds. Around 10-25 % of bird species are benefited from deadwood and habitat trees. Many threatened organisms in the forest ecosystems depend upon these habitat trees. The role of old trees has caught the attention of humans as they play an important role in managing the habitat of a forest. They also have consequently acquired a symbolic role in the life of humans, either directly or indirectly (Butler *et al*., 2013). Every taxon has its role, and single biota reflects its importance. Birds have been generally regarded as a critical factor in monitoring the biodiversity of an area. Birds are unlikely to be an indicator taxon for other biotas. They can be used to monitor greater or less effort than other biotic components (Mac Nally *et al*., 2004). Birds also help monitor climate changes, habitat fragmentation, with a mounting focus on habitat quality (Major *et al*., 2001).

The diversity and abundance of birds are strongly linked with tree diameter, height, bark thickness, dried wood canopy, and tree age. Old trees provide cracks, wide cavities, fruits, loose bark, and other microhabitats that attract birds for feeding, foraging, roosting, and nesting. Thus, old trees provide dwelling grounds for bird diversity. Habitat trees are known for their role in forest biodiversity and the ecological services provided by them. As a result, foresters consider them optimistically. These trees offer habitat for various species, and when they fall, they become a source of woody debris and finally, through decay, contribute to maintaining ecosystem functions via nutrient cycling (Larrieu and Cabanettes, 2012).

During the last few decades, the number of habitat trees has increased in some parts of developed countries. However, the conservation of older, dead, and dried trees is part of government policies applicable to the government-owned forest in India, not favoring the conservation of these trees. The future of habitat trees on private lands in urban areas and villages will influence the conservation policies. So, conservation policies will be needed to protect these habitat trees. The old trees act as a substrate for a significant part of forest biodiversity, so particular attention should be given to old trees. On realizing the importance of old trees, several countries have promoted their preservation and are being inventoried. Therefore, coordinated measures should be taken to protect habitat trees and their microhabitats, and it should be of prime concern in the present day scenario (Saresh *et al*., 2018).

River buffer strips provide a wide range of ecosystem services, including enhancing the aesthetic value, protecting biodiversity, mitigating pollution, and provide freshwater systems. The multifunctional nature of river systems makes it difficult to develop management prescriptions, results in complex plans with a review of parameters like conflicts, interactions, and synergies between the services offered (Cole *et al*., 2020). Such a diverse ecosystem provides a range of habitats for different species and leads to higher species richness in the area. Avian diversity also gets influenced, and habitat heterogeneity provides higher avian abundances and diversity in such areas (Lorenzón *et al*., 2016). The presence of non-native plants species may alter riparian community's structure by competing with native species and hindering the restoration of degraded areas (Brooks *et al*., 2004). Punjab is not an exception. Many invasive species have entered into Punjab via anthropogenic activities (Dhami, 2018). The interacting hydrological and ecological processes of functional riparian support biodiversity and provide critical ecosystem services, including flood, water, and quality habitat (Cole *et al*., 2020). The habitat structure of river Beas has got deformed up to some extent, and the hydrology of the river has been changed for irrigation and electricity production (Moza and Mishra, 2007). The water quality index of River Beas has also decreased towards Harike (Kumar *et al*., 2017). River Beas was declared a conservation reserve in 2017 under section 36A of the Wildlife Protection Act 1972 and designated as a Ramsar site in 2019 (Anonymous, 2019; RIS, 2020). A wide range of efforts is required to understand, monitor, and restore the habitats along the river. The nesting of birds in the riparian zone of the river is an essential part of sustaining the avian diversity in the area. Restoration of hydrologic function unrelated to riparian deciduous vegetation for nesting and foraging can improve habitat quality for birds (Campos *et al*., 2020). Therefore the present study has been done to monitor and collect the crucial information required for the development of conservation strategies for the newly built conservation reserve.

Conclusion and recommendations

Effective natural conservation of a river should focus on management efforts emphasize hydrology, biology, water quality, and morphology of the river (Addy *et al*., 2016). In the case of the river Beas Conservation Reserve, it should be taken into consideration that the river flows through a state practicing intensive agriculture. The floodplain, and more specifically the riparian zone of the river, is the last shelter for the wildlife diversity, specifically to the habitat specialist bird species in the state. Along with this, Beas Conservation Reserve connects the two wetlands of international importance (Harike and Pong) harboring rich avian diversity and hosts thousands of migratory birds every year. It acts as a corridor for the faunal diversity to move between the two, especially avian and fish species. There is a need for a more scientific approach to conserving the overall habitat of the river. On the basis of the above study, the following management strategies are recommended:

- Agricultural land use and landscape structure near the floodplain zone of the river is principal component for overall avian density, richness, and diversity. The state has rich avian diversity with a significant number of habitat specialist species that are not found in an agricultural landscape. The minimum natural areas like riparian zones of the river and small seasonal and perennial ponds in flood plains of the river should be protected.
- Agriculture intensification along the rivers negatively impacts the habitat specialist bird species; however, it seems to favors generalist and insectivore species. Paddy fields may increase the diversity in the region, whereas crops like maize should be avoided near the river zone as it may

attract more generalist species that may damage the crop and create competition for the species living in the riparian zone. However, more deep studies would be required to understand the variation in species diversity and its impact on agriculture near rivers.

- Native trees like Neem (*Azadirachta indica*), Banyan (*Ficus benghalenesis*), Jamun (*Syzygium cumini*), Mulberry (*Morus alba*), Pipal (*Ficus religiosa*), and Sheesham (*Dalbergia sissoo*) harbor a rich avian diversity in Punjab; hence these species should be promoted for plantation in the riparian zone of the river.
- Generally, the banks of the river are covered with native grasses and native tree species. Native vegetation, including trees and grasses, provides suitable habitat for native breeding birds. Therefore plantation of native grass species during plantation drives should be taken into consideration along the bank of the river.
- The most prevalent tree species in agroforestry of Punjab are Poplar (*Populus deltoides*), Eucalyptus (*Eucalyptus tereticornis*), Dek (*Melia composita* and *M. azedarach*), Leucaena (*Leucaena leucocephala*), Kadam (*Anthocephalus cadamba*), and Teak (*Tectona grandis*). Poplar has been adopted at large scape by farmers for agroforestry, but the poplar plantation near riparian zones should be avoided as it negatively affects the avian diversity of the region. Agro-forestry using Dek, Leucaena, Kadam, and Teak should be more favorable for conservation and increase the avian diversity along the river in agricultural fields.
- Large-scale monocultures of exotic non-native trees with a short rotation period can have negative implications, whereas mixed plantations of native trees, including orchards, should be promoted in the regions adjoining agroforestry areas along the river.
- Urbanization along the rivers is inevitable, which comes with the problem of industrial pollutants, sewage waste, and EMR in the form of mobile towers. The government is already working on industrial pollutants and sewage waste; however, there are no guidelines for mobile towers in the region. Studies in the region have shown low avian abundance and breeding success near mobile towers and high voltage power transmission towers. It will be appropriate to avoid the installation of mobile towers near the conservation reserve.
- Sensitization of the local people living along the river is important at the first step. This will help deal with the first problem of encroachment of the land, which is the last host for specialist species.
- The region between Talwara barrage and Mirthal has rich faunal and floral diversity; however, there is a scarcity of water between these courses of the river. Without sufficient water supply, it will be difficult to keep the river's habitat healthy and functional; therefore, there is a need to increase the amount of water released into the river.
- The river merges with Satluj at Harike, forming a large wetland known as Harike wetland. This region of the river has one of the richest avian diversity in north India. Land-use changes and decreases in water levels are responsible for the loss of ecosystem services of wetlands around the world. Harike is a wetland of international importance; however, land-use changes have been

reported in recent times in the wetland area. It may alter the avian diversity of the wetland, so it needs to be addressed as early as possible.

- Generally, avian abundance is higher on rivers sides and is positively correlated with vegetation and stream size. Both water birds and terrestrial birds get benefited from riparian nutritional pathways along the rivers. Around 10-25 % of bird species are benefited from deadwood and habitat trees. The natural habitat of the riparian zone of the river consists of native trees of all age groups, shrubs, and grasses. Older trees, alive or dead, need to be protected in the riparian zone as they ecological niches (microhabitats) in the form of cavities, epiphytes, sap runs, bark pockets, cracks, trunk rot, etc. for a number of avian species.
- The presence of non-native and invasive plants species may alter species community structure by competing with native species and hindering the restoration of degraded areas. Many invasive species have entered into Punjab via anthropogenic activities, including agriculture. Constant monitoring is required to protect the region for maintaining a healthy ecosystem along the river.

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Chapter [12]

Waterbird survey at Bheemgoda Barrage and Missarpur Ganga Ghat wetlands of Haridwar district in Uttarakhand, India

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Abstract

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. An attempted was made to know the health of the Ganges's wetlands ecosystem, waterbird survey was conducted between January 2019 and December 2020 in Haridwar district. Total of sixty three waterbird species, belong to fourteen families reported during the study. Out of these duck family was dominated among the families. Six species River lapwing (*Vanellus duvaucelii*), Black-necked stork (*Ephippiorhynch usasiaticus*), Woolly-necked stork (*Ciconia episcopus*), Painted stork (*Mycteria leucocephala*), River tern (Sterna aurantia) and Black-headed ibis (*Threskiornis melanocephalus*) were near threaten, One specie was reported endangered Black-bellied tern (*Sterna acuticauda*), and One vulnerable Common pochard (*Aythya ferina*) categories as per IUCN Red-list data. As interesting finding, we reported Asian Open bill stork (*Anastomus oscitans*) and Black-bellied tern (*Sterna acuticauda*) avian species first time in Haridwar Wetlands. The presence of avian species diversity increases the regional avian diversity of district Haridwar and emphasizes to prepare a scientific conservation strategy for the IUCN categorized waterbird species.

Keywords Biodiversity, Haridwar, Uttarakhand, Waterbirds, Wetlands

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Introduction

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. Wetlands are one of the most productive ecosystems of our natural environment (Ghermandi *et al*., 2010) and supported by many creatures, including birds. Wetlands are neither truly aquatic nor terrestrial; generally, it depends on seasonal variability and this transitional character of wetland creates complexity to define the boundaries of wetlands. Although, wetland has been defined as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar Convention, 1971/Article 1.1). As per the ancient records many human civilizations established near the riverine system or wetland areas because they fulfilling basic needs such as (water and food). In addition, wetlands have great cultural, social, ecological and economic values (Ramachandra *et al*., 2002). On the other hand; it enhances the diversity with reference to flora and fauna of that area due to their geographical location and habitat characteristics. The biological diversity of wetlands depends on the water quality and the vegetation around the wetland for the survival of the species (Buckton, 2007). In India, about 15.26 million hectares of land is cover as wetland (Prasad *et al*., 2002; SAC, 2011). These wetlands support the existing and growth of various flora and fauna. Total 1340 bird species have been recorded in India (Ali and Ripley, 1987; Grimmett *et al*., 2016) including 38 endemic species (Praveen *et al*., 2016). Of the total, about 310 species have been considered as wetland birds (Kumar *et al*., 2005).

Globally, habitat destruction (via land-use change) is one of the major issues that have been identified as the causes responsible for the loss of biodiversity (Butchart *et al*. 2010, Sala *et al*., 2000). Indian is also not untouched with degradation of wetlands and the degradation rate is high as compare to others. There are several causes have been identified that are responsible for the wetland degradation. Out of these, some are unsustainable agriculture practice, construction of human settlement around the wetlands, cattle grazing, and the construction of dams are very visible and well-known. In addition, increasing human population, unsustainable development, and lack of awareness are responsible causes to decline the wetland habitat (Ramachandra *et al*., 2002). Some studies have been shown the Natural calamities are also accountable for the wetland degradation (Bennett *et al*., 2018). Thus, wetland degradation directly influences the population of flora and fauna; it has been reported that the population of wetland birds has declined significantly from the Indian wetlands (Saikia and Bhattacharjee, 1993).

Several studies have been mentioned that wetland provides a unique habitat for many residential bird and migratory bird species (Zhijun, *et al*., 2010; Ghasemi, *et al*., 2012; Shao *et al*., 2014; Bhatt, 2015; Saini *et al*., 2017; Arya *et al*., 2019; Wanna *et al*., 2020, Arya *et al*., 2020). Some studies in India (Kaushik *et al*., 2013, Bhatt *et al*., 2015, Saini *et al*., 2017, Arya *et al*., 2019) have been reported wetland provides good shelter, food, and enhance the waterbird diversity. However, many wetlands in India such as Bharthpur wildlife sanctuary, Rajasthan, coastal areas of Gujarat and many more wetlands have been reported that host the thousands of migratory birds come from western and European countries

(Agarwal, 2011). Many types of water migratory birds have migrated in India as winter visitors through the different flyways.

Now a day, these wetlands are degrading through various anthropogenic activities therefore a periodic survey on wetland avian species is required to understand the health of natural ecosystem. Water bird survey play a key role to identified the international importance of any types of wetlands (Arya *et al*., 2020). Very few studies have been conducted in Uttarakhand wetland area namely Missarpur Ganga Ghat and Bheemgoda barrage (Bhatt *et al*., 2015; Saini *et al*., 2017, Arya *et al*., 2019). The current water-bird survey was made to understand the status (present/absent basis) of waterbird species in wetlands of Haridwar district, Uttarakhand. However, a periodic monitoring on avian diversity and abundance is useful to understand the status of an ecosystem and restoration planning for habitat.

Bheemgoda Barrage and Missarpur Ganga Ghat wetlands of Haridwar

The present study was conducted between January 2019 and December 2020 in Haridwar district of Uttarakhand. The Bheemgoda barrage, is situated at the upstream region (29°58′ N, 78°13′E, 249.7 masl) between the Neel Dhara and the tributaries of the Ganga River under biogeographic province 4.8.4 (Indo-Gangatic Monsoon Forest), covering an area of about 2.5 km^2 area, while the Missarpur wetland situated about 8 km away at the downstream from Bheemgoda Barrage comprising an area of about 1.5 km^2, under biogeographic province 4.8.4 (Indo-Gangatic Mon-soon forest). A rich and diverse vegetation cover is available across the wetland, although some aquatic vegetation species such as *Potomageton pectinatus*, *Eichhornia crassipes* and *Typha elephantine* with a tree species, *Dalbergia sissoo* is common in the region of the Bheemgoda barrage (Figures 1 and 2).

Figure 1. Map of Haridwar district selected for waterbird survey area in of Uttarakhand.

Figure 2. (A).Bheemgoda barrage (B). Missarpur wetland sites (Source: Google earth).

On the other hand, Missarpur wetland has dominated with aquatic vegetation namely *Eichhornia crassipes, Typha elephantine*, *Ipomeafis-tulosa*, *and Potomageton pectinatus*. The *Dalbergia sissoo* tree species is dominated with mixed tree species in the area of Missarpur wetland. Haridwar has three prominent seasons like winter (October to March), summer (April to June) and Monsoon (July to September) and the temperature ranges from minimum of 4°C in winter to a maximum 38 °C in summer (Saini *et al*., 2017; Arya *et al*., 2019). The waterbird survey was conducted from January 2019 to December 2020. Point count methods (Bibby *et al*., 2000) were applied for waterbird counting. The survey was completed morning 07:00 am to 11:00 am and evening 04:30 pm to 06:30 pm during summer season and between 10:00 am to 12:00 pm (morning) and 04:00 pm to 07:00 pm (evening) during winter seasons. The photographs of waterbird species were taken by the Canon SX60HS model camera and identified the species by the using field guide book (Grimmett *et al*., 2016).

Status of waterbirds at Bheemgoda Barrage and Missarpur Ganga Ghat wetlands of Haridwar

Total of 63 waterbird species belonging to 14 families were reported during the study period (Table 1). Anadiae family which contributes, duck spices were dominant among the waterbird species (Figure 3). However, Black Cormorant were reported dominate in Bheemgoda barrage (Figure 4). Both the wetland habitat total 37 resident, 26 winter migratory bird species were reported (Figure 5). During survey, it was reported that most of the migratory water bird species reaches both wetland habitats till the month of November and stay here at least next 5 months. In addition, Six Near threaten namely River lapwing (*Vanellus duvaucelii),* Black-necked stork *(Ephippiorhynchus asiaticus),* Woolly-necked stork *(Ciconia episcopus),* Painted stork *(Mycteria leucocephala), River tern (Sterna aurantia)* and Black-headed ibis *(Threskiornis melanocephalus)*.

Figure 3. A Flock of duck species in Missarpur wetland of Haridwar district.

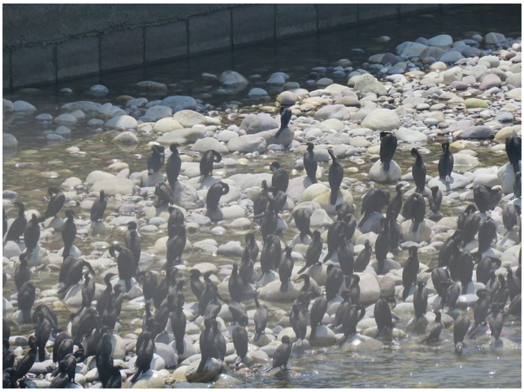

Figure 4. Black cormorant species flock in Bheemgoda barrage wetland

Table 1. Checklist of Water Birds of Haridwar, Uttarakhand, India.

Family	Common Name	Scientific Name	Status	IUCN status	IWPA Schedule
Anatidae	Lesser Whistling-Duck	*Dendrocygna javanica*	WV	LC	IV
	Bar-headed Goose	*Anser indicus*	WV	LC	IV
	Ruddy Shelduck	*Tadorna ferruginea*	WV	LC	IV
	Gadwall	*Mareca strepera*	WV	LC	IV
	Indian Spot-billed Duck	*Anas poecilorhyncha*	WV	LC	IV
	Mallard	*Anas platyrhynchos*	WV	LC	IV
	Northern Pintail	*Anas acuta*	WV	LC	IV
	Green-winged Teal	*Anas crecca*	WV	LC	IV
	Red-crested Pochard	*Netta rufina*	WV	LC	IV
	Common Pochard	*Aythya ferina*	WV	VU	IV
	Tufted Duck	*Aythya fuligula*	WV	LC	IV
	Common Merganser	*Mergus merganser*	WV	LC	IV
Anhingidae	Gray Heron	*Ardea cinerea*	R	LC	IV
	Purple Heron	*Ardea purpurea*	R	LC	IV
Ardeidae	Great Egret	*Ardea alba*	R	LC	IV
	Intermediate Egret	*Ardea intermedia*	R	LC	IV
	Little Egret	*Egretta garzetta*	R	LC	IV
	Cattle Egret	*Bubulcus ibis*	R	LC	IV
	Indian Pond-Heron	*Ardeola grayii*	R	LC	IV
	Striated Heron	*Butorides striata*	R	LC	IV
	Black-crowned Night-Heron	*Nycticorax nycticorax*	R	LC	IV
Burhinidae	Eurasian thick-knee	*Burhinusoedienemus*	R	LC	IV
	Indian thick-knee	*Burhinusindicus*	R	LC	IV
	Great thick-knee	*Esacusrecurvirostris*	R	LC	IV
Charadriidae	Northern Lapwing	*Vanellus vanellus*	R	NT	IV
	River Lapwing	*Vanellus duvaucelii*	R	NT	IV
	Yellow-wattled Lapwing	*Vanellus malabaricus*	R	LC	IV
	Red-wattled Lapwing	*Vanellus indicus*	R	LC	IV
	White-tailed Lapwing	*Vanellus leucurus*	R	LC	IV
	Little Ringed Plover	*Charadrius dubius*	WV	LC	IV
Ciconiidae	Asian Open bill	*Anastomus oscitans*	R	LC	IV
	Black Stork	*Ciconia nigra*	WV	LC	IV
	Woolly-necked Stork	*Ciconia episcopus*	R	NT	IV
	Black-necked Stork	*Ephippiorhynchus asiaticus*	WV	NT	IV
	Painted Stork	*Myctria leucocephala*	R	NT	IV

Table 1. Continued...

Family	Common Name	Scientific Name	Status	IUCN status	IWPA Schedule
Hirundinidae	Gray-throated Martin	*Riparia chinensis*	R	LC	IV
	Barn Swallow	*Hirundo rustica*	R	LC	IV
	Wire-tailed Swallow	*Hirundo smithii*	R	LC	IV
Jacanidae	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	R	LC	IV
	Bronze-winged Jacana	*Metopidius indicus*	R	LC	IV
Laridae	Black-headed Gull	*Chroicocephalus ridibundus*	WV	LC	IV
	Brown-headed Gull	*Chroicocephalus brunnicephalus*	WV	LC	IV
	Pallas's Gull	*Ichthyaetus ichthyaetus*	WV	LC	IV
	Caspian Gull	*Larus cachinnans*	WV	LC	IV
	Little Tern	*Sternula albifrons*	WV	LC	IV
	River Tern	*Sterna aurantia*	WV	NT	IV
	Black-bellied tern	*Sterna acuticauda*	R	EN	IV
Pha-lacrocoracidae	Little Cormorant	*Microcarbo niger*	R	LC	IV
	Great Cormorant	*Phalacrocorax carbo*	R	LC	IV
Podici-pedidae	Great Crested Grebe	*Podicep scristatus*	WV	LC	IV
	Little Grebe	*Tachybaptus ruficollis*	R	LC	IV
Rallidae	Eurasian Moorhen	*Gallinula chloropus*	R	LC	IV
	Eurasian Coot	*Fulica atra*	WV	LC	IV
	Gray-headed Swamp hen	*Porphrio poliocephalus*	WV	LC	IV
	Water cock	*Gallicrex cinerea*	R	LC	IV
	Common moorhen	*Gallinula chloropus*	WV	LC	IV
Recurvirostri-dae	Black-winged Stilt	*Himantopus himantopus*	R	LC	IV
	Pied Avocet	*Recurvirostra avosetta*	R	LC	IV
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	R	LC	IV
	Green Sandpiper	*Tringa ochropus*	R	LC	IV
	Common Greenshank	*Tringa nebularia*	R	LC	IV
	Marsh Sandpiper	*Tringa stagnatilis*	R	LC	IV
	Common Redshank	*Tringa totanus*	R	LC	IV

R = Staying in one place all the year, non-migratory; WV = A winter migrant to India which breeds in Eurasia and visits India in winter, LC= Least Concern, NT= Near Threatened, EN= Endangered, IUCN= International Union for Conservation of Nature

One endangered Black bellied tern (*Sterna acuticauda*), and one vulnerable species Common Pochard (*Aythya ferina*) categories as per IUCN red-list were also reported during survey. Some of the threaten species namely River tern (*Sterna aurantia*), River lapwing (*Vanellus duvaucelii*), and Black-necked Stork (*Ephippiorhynchus asiaticus*) are shown in the Figures 6a-6c.

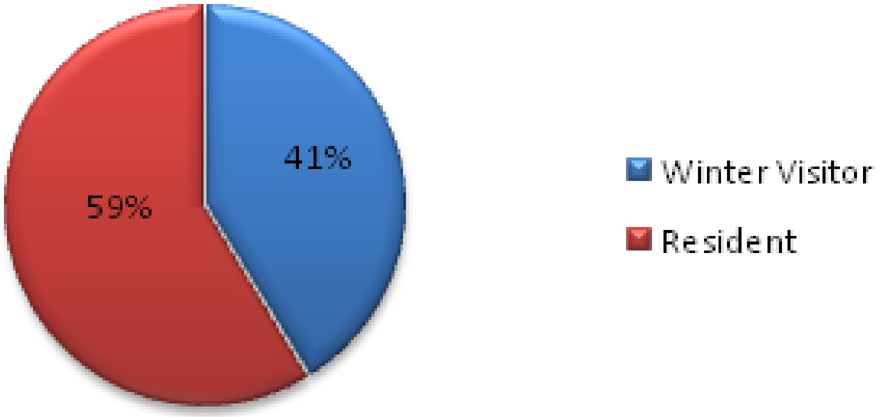

Figure 5. Status of waterbird species (in %) from the Bheemgoda barrage and Misserpur wetland habitat of the study area.

Figure 6a. River tern (*Sterna aurantia*)

Figure 6b. River lapwing (*Vanellus duvaucelii*)

Figure 6c. Black-necked Stork (*Ephippiorhynchus asiaticus*)

Conclusion

The presence of residence and migratory water bird species enhance the local avian biodiversity of the Haridwar district. The availability of near threaten, and endangered species in the study area indicates the both the wetlands are suitable or less disturb habitat for the waterbird species. The available water bird species data will helpful for the researchers and this base line data will also helpful for the further study in Haridwar wetland.

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Chapter [13]

An updated checklist of fauna of Binsar wildlife sanctuary of Uttarakhand (Western Himalaya), India

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Abstract

The present checklist on faunal composition is a compilation of published records on faunal diversity of mammals, Aves and insects mainly between the years 1998-2021 from the Binsar Wildlife Sanctuary in State Uttarakhand, India. The sanctuary is known for its wide range of mammals, birds and insect species. The list comprised 16 species of mammals belonging to five orders under nine families, 173 species of birds belonging to 12 orders under 45 families and 121 species of insects belonging to eight orders under 36 families. It is intended that the checklist would help in obtaining a holistic view of faunal diversity, mainly mammals, birds and insects so that their status could be monitored and maintained at various levels in the sanctuary. The sanctuary is low profiled in terms of biodiversity conservation and scientific management, and still unexplored or under-explored in relation to the faunal diversity. Therefore, the findings reported in the present study promisingly emphasize the ongoing threats to the biological diversity of the Binsar wildlife sanctuary of Uttarakhand (Western Himalaya), India which needs an immediate attention in order to conserve the residing faunal species.

Keywords Diversity, Fauna, Himalaya, Insects

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Introduction

The hill state of Uttarakhand located in Western Himalayan Region covers an area of 53,483 sq. km stretched between 28º43′ to 31º28′ North Latitudes and 77º34′ to 81º03′ East Longitudes. Based on the administrative attributes, there are 13 districts covered in Garhwal and Kumaon Hills (Arya and Verma, 2020). With approximately 64.79% of total land under forest cover, area of about 9,885 sq. km (18.48%) of the state has been insulated by the creation and management of protected area network for *in situ* conservation of biodiversity and fragile ecosystems (Rodgers and Panwar, 1988). The existing network of protected areas in the Himalayan Region covers about 6% of the entire range, and most of them suffer from human and biotic pressures and lack of sufficient management inputs as well as adequate conservation plans (Rawal and Dhar, 2001). The protected areas located in the Indian Himalayan Region especially those which are low profiled ones hold immense potential to enhance the components of floral and faunal representativeness, integrity and human sustenance in the region (Rawal and Dhar, 2001). At present there are six national parks, seven wildlife sanctuaries and four conservation reserves in the state Uttarakhand.

Binsar Wildlife Sanctuary (BWLS) represents one of the oldest protected landscapes in the Kumaon region, and it is a natural habitat for several flora and fauna. The sanctuary recently received the attention of government and non-government organizations, and is being developed as a hot tourist destination in the calm and pristine environment of the Kumaon Himalaya. Protected areas of Indian Himalayan Region offer unique habitats for studying the diversity of different groups of mammals, birds, insects and other faunal groups. Many scientific records regarding the flora, wildlife, birds and various aspects of ecological and environmental studies have been published by workers of different organizations of international and national repute from the BWLS (Ilyas, 1998; Ilyas, 1999; Khan *et al*., 2000; Sultana and Khan, 2000; Ilyas and Khan, 2001, 2004, 2005; Islam and Rahmani, 2004; Singh and Khushwah, 2011; Kala and Majila, 2013; Kala and Kothari, 2013; Uttarakhand Forest Department, 2014, Bhalla *et al*., 2015; BirdLife International, 2021; Mohan and Sondhi, 2014, 2015, 2017; Shahabuddin *et al*., 2017; Bhalla *et al*., 2020; Lepage, 2021). Similarly, studies on different aspects of biodiversity have been carried out in the BWLS of Himalaya viz. natural resource utilization (Majila and Kala, 2010), ecosystem functions (Majila *et al*., 2005), forest conservation (Rawat *et al*., 2013), community-based eco-tourism (Bhalla *et al*., 2017), floristic analysis (Khan and Arya, 2017) and human-wildlife conflicts (Kala and Kothari, 2013). Recently, studies on the ecology and behavior of insects have been carried out by Ghosh *et al*. (2011, 2018), Arya *et al*. (2016a, b), Arya *et al*. (2017), Tamta (2017), Arya *et al*. (2018a, b), Arya *et al*. (2019) and Arya *et al*. (2020) in different locations of the BWLS. However, comprehensive attempts to understand the faunal diversity including mammals, birds and insects are still lacking from the sanctuary.

A detailed checklist representing faunal repository is essential, and is required for the scientific and planned management of species in the BWLS. Therefore, the purpose of this study was to examine and evaluate the reported faunal diversity in the BWLS through considering published literature and authentic accessible reports in order to establish a reliable biodiversity data source for future conservation in the protected area. The present study also aims to generate information for conservation authorities regarding the development and management of the sanctuary.

Binsar Wildlife Sanctuary

It is stretched between 29°39′ to 29°44′ North Latitudes and 79°41′ to 79°49′E Longitudes is located in districts Almora and Bageshwar of Uttarakhand at an altitude of 1200 to 2500 meters above sea level in Kumaon Himalaya (Figure 1). Binsar is a fascinating spot that offers a majestic glimpse of the snowcapped Indian Himalayan peaks namely-Nanda Devi, Trishul and Panchachuli, presenting a unique experience to its visitors. With the geographical area of 47.67 sq. km, the sanctuary has core zone (4 km^2) and buffer zone (43.67 km^2). No human activity is allowed in the Core Zone (Restricted Zone). Prior to India's Independence, it was notified as ''Protected Forest'' in 1893 and later upgraded as ''Reserve'' Forest in 1897. After Independence in 1947, its status was revived to ''Wildlife Sanctuary'' by the Government of India in the year 1988.

Zoning within BWLS

Zone permits focus on specific areas in order to accommodate different management needs as per the requirement of the protected landscape. Within BWLS, different areas catered different needs and demands from diversified sections of the society (Bhalla *et al.*, 2015). Therefore, to meet these requirements zonation of the sanctuary was framed legally (Binsar Management Plan, 2000-2010) in a most scientific, sustainable and logical manner by the regional forest department in consultation with the villagers and concerned stakeholders as follows:

- **Core zone:** It is actually a mini core zone (4 km^2) that comprises forest area of strategic importance, mainly different oak tree species along with its rich under storey biodiversity. Extraction of forest produce in form of right and concessions is seldom allowed.

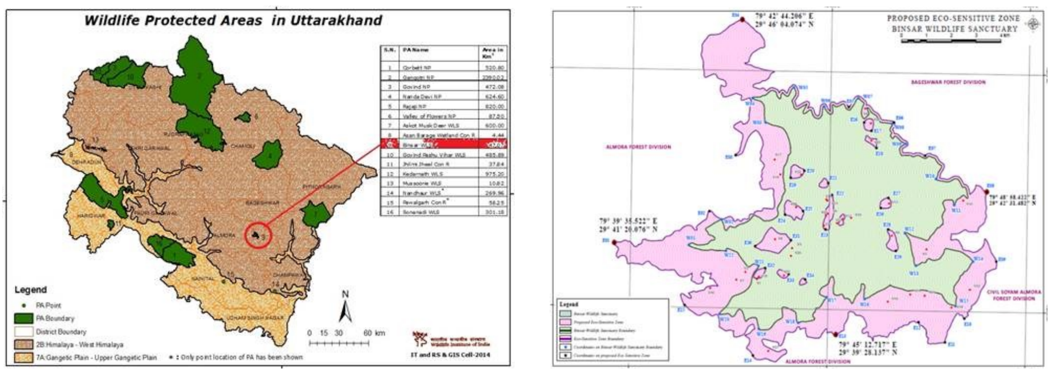

Figure 1. Location of Binsar Wildlife Sanctuary in Uttarakhand (Source: WII, 2014).

- **Tourism zone:** It comprises of the motor road passing through Binsar compartments, which terminates at the forest rest house. From here a nature trail is made upto Jhandi Dhar (Zero-point), highest point of BWLS, from where a magnificent view of mighty Himalayas is seen. All resort accommodations and four villages lay within this zone, that provide as tourist attractions.
- **Buffer zone:** Rest of the areas not covered in above two zones fall under the Buffer zone. These areas are open for regulated grazing and address the rights and concessions requirement of villagers. At present there are two entry gates for visitors into BWLS, one at Ayarpani, and other at Dhaulchina, which lay within this zone along with two villages.
- **Eco-development zone:** Covers the area up to 5 km from the boundary of BWLS. It comprises of a several villages and few resorts for visitor accommodations.

Climate

The climatic conditions prevailing in the BWLS range from temperate to sub-arctic. Winters are very cold and the region receives heavy snowfall during December-February. The mean monthly temperature ranges from 2.2°C to 15.5°C during winter and from 17.20°C to 26.6°C during summer, with the average rainfall of more than 1200 mm (Sharma *et al*., 1999). The mean maximum temperature varies from 14.30°C (January) to 31.73°C (June) and the mean minimum temperature fluctuates from 0.2°C (January) to 12.30°C (August). During the coldest months of January and February, the area receives heavy dew at night. Snowfall usually starts in the middle of December and continues till the end of February. The monsoon generally begins after mid June. Sometimes it may start around late May or mid-July and last till the end of September. The heaviest rainfall usually occurs in July and August (Kala and Majila, 2013). Relative humidity varies along aspects and types of vegetation in the BWLS. The average relative humidity varies on a monthly basis from 36% to 76% in the Chir Pine forest during April and August, respectively. In the Oak forest, the relative humidity varies between 49% in April and 87% in August (Majila, 1992 and Majila *et al*., 2005).

Geology, geomorphology and soil

The diverse climatic, geographical, and topographical conditions have shaped the diverse forest vegetation and wildlife species in BWLS. On an average, the soil is very rich in organic matter that contains a high proportion of plant nutrients**.** The slopes vary from steep to very steep. The terrain has been shaped by the action of running water. Throughout the sanctuary, the terrain is hilly and characterized by deep ravines, crevices and elevated ridges (Bhalla *et al*., 2015). Geologically, the sanctuary falls under the Inner Lesser Himalayan zone, which mainly comprises unfossiliferous sedimentary rocks of various ages, that is, from Precambrian to Paleozoic (Valdia, 1976). The rocks are predominantly made up of the Korl group of Paleozoic age, which are composed of granite, granodiorite, graphite, schist, shale-quartzite, and quartzite (Gansser, 1964).

Flora of Binsar

Binsar represents the characteristic floral element of moist temperate type of forest (Saxena and Singh, 1982). BWLS is known for its wide variety of flora including 40 species of trees followed by 26 shrubs, 50 herbs, 19 grasses and six ferns (Ilyas, 1998). The forested hilltops and slopes in the sanctuary are covered with Chir Pine (*Pinus roxburghii*), Banj Oak (*Quercus leucotrichophora*), and Rhododendron (*Rhododendron arboreum*) as pure stands or as mixed forests. Pure pine forests are found at the altitude ranging between 1600 m to 1900 m, while mixed forests of pine and oak are distributed between 1900 m to 2100 m altitudes. Pure oak and mixed-oak forests (*Quercus leucotrichophora* and *Quercus floribunda*) are present between 2100 m to 2400 m altitudinal range in the sanctuary (Majila and Kala, 2010). In the more recent years, Rawat *et al*. (2013) reported a total of 147 plant species in BWLS of which 90 species were herbs, 20 were shrubs and 27 were trees. Among them, there are 12 species with edible fruits, three species are timber yielding, 26 are good fuel and fodder, eight have sacred values and 46 are medicinally important.

Data collection, compilation and evaluation

Secondary data on recorded faunal species of mammals, birds and insects was obtained from the available published literature (Ilyas, 1998; Ilyas, 1999; Khan *et al*., 2000; Sultana and Khan, 2000; Ilyas and Khan, 2001, 2004; Islam and Rahmani, 2004; Ilyas and Khan, 2005; Majila and Kala, 2010; ZSI, 2010; Singh and Khushwah, 2011; Ghosh *et al*., 2011; Kala and Majila, 2013; Kala and Kothari, 2013; Rawat *et al*., 2013; Mohan and Sondhi, 2014; Uttarakhand Forest Department, 2014; Bhalla *et al*., 2015; Mohan and Sondhi, 2015; Arya *et al*., 2016a, b; BirdLife International, 2021; Bhalla *et al*., 2017; Khan and Arya, 2017; Mohan and Sondhi, 2017; Arya *et al*., 2017; Tamta, 2017; Ghosh *et al*., 2018; Arya *et al*., 2018a, b; Arya *et al*., 2019; Arya *et al*., 2020; Shahsbuddin *et al*., 2017; Arya and Verma, 2020; Bhalla *et al*., 2020 and Lepage, 2021). The species in the checklist were catalogued alphabetically into orders, families, genera and all the species were listed with their accepted names as such with correct spellings. However, an updated classification and latest scientific names of bird species were followed as per Grimmett *et al*. (2011).

Taxonomic composition of faunal species in BWLS

BWLS is known for its wide range of mammals, birds and insect species. The compilation of data from available literature resulted in 16 species of mammals belonging to five orders under nine families, 173 species of birds belonging to 12 orders under 45 families and 121 species of insects belonging to eight orders under 36 families as reported from BWLS of Uttarakhand.

Mammalian diversity

India hosts rich diversity of flora and fauna. The total 410 species of mammals in India comprises about 8.9% of all known mammal species worldwide (Nameer, 1998). BWLS is home to 16 high altitude species of mammals (Table 1) including Common Leopard (*Panthera pardus*), Jungle Cat (*Felis chaus*),

Table 1. Mammal species composition of Binsar Wildlife Sanctuary.

Order/ Family	Common Name	Scientific Name	Status: IW(P)A and IUCN
CARNIVORA/ Falidae	Common Leopard	*Panthera pardus* (Linnaeus)	IW(P)A: Schedule I, Part I VU (Nationally), DD (Globally)
CARNIVORA/ Falidae	Jungle Cat	*Felis chaus* Schreber	IW(P)A: Schedule II LRnt (Nationally), DD (Globally)
CARNIVORA/ Ursidae	Himalayan Black Bears	(*Selenarctos thibetans*)	VU (Nationally), DD (Globally)
CARNIVORA/ Canidae	Jackals	*Canis aureus* Linnae-us	IW(P)A: Schedule I, Part I LRnt (Nationally), DD (Globally)
CARNIVORA/ Canidae	Red Fox	*Vulpes vulpes* (Linnaeus)	IW(P)A: Schedule II, Part II LRlc (Nationally), DD (Globally)
CARNIVORA/ Mustelidae	Yellow-throated Mar-tin	*Martes flavigula* (Baddaert)	IW(P)A: Schedule II, Part II LRnt (Nationally), DD (Globally)
ARTIODAC-TYLA/ Bovidae	Goral	*Nemorhaedus goral* (Hardwicke)	IUCN: LR/nt
ARTIODAC-TYLA/ Bovidae	Serow	*Nemorhaedus suma-trensis* ((Bechstein)	IW(P)A: Schedule I, Part I VU (Nationally), DD (Globally)
ARTIODAC-TYLA/ Cervidae	Barking Deer	*Muntiacus muntjak* (Zimmermann)	IW(P)A: Schedule III LRlc (Nationally), DD (Globally)
ARTIODAC-TYLA/ Suidae	Wild Boars	*Sus scrofa* Linnaeus	IW(P)A: Schedule III LRlc (Nationally), DD (Globally)
PRIMATES/ Cer-copithecidae	Rhesus Macaques	*Macaca mulatta* (Zimmermann)	IW(P)A: Schedule II LRlc (Nationally), DD (Globally)
PRIMATES/ Cer-copithecidae	Common Langurs	(*Presbytus entellus*)	IW(P)A: Schedule II LRlc (Nationally), DD (Globally)
RODENTIA/ Sciuridae	Giant Flying Squirrel	*Petaurista petaurista* (Pallas)	Not Known
RODENTIA/ Sciuridae	Kashmir Flying Squirrel	*Hylopetes fimbriatus*	Not Known
RODENTIA/ Hystricidae	Indian Crested Por-cupine	*Hystrix indica* Kerr	IW(P)A: Schedule IV LRlc (Nationaly), DD (Globaly)
LAGOMORPHA/ Leporidae	Black-napped Hare	*Lepus nigricollis* Cu-vier	DD (Nationally & Globally)

(Abbreviations used: IW(P)A= Indian Wildlife (Protection) Act, VU= Vulnerable, LR/nt or LRnt= Lower Risk near threatened, LRlc = Lower Risk least concern, DD= Data Deficient, Schedule I, II, III, IV of Indian Wildlife (Protection) Act, 1972)

Himalayan Black Bear (*Selenarctos thibetans*), Jackal (*Canis aureus*) and red fox (*Vulpes vulpes*). Major Ungulate species includes Gorals (*Nemorhaedus goral*), Barking Deer (*Muntiacus muntjak*), Serows (*Nemorhaedus sumatrensis*) and Wild Boars (*Sus scrofa*). Other mammal species in the sanctuary are Rhesus Macaques (*Macaca mulatta*), Common Langurs (*Presbytus entellus*), Giant Flying Squirrel (*Petaurista petaurista*), Kashmir Flying Squirrel (*Hylopetes fimbriatus*), Indian Crested Porcupine (*Hystrix indica*) and Black-napped Hare (*Lepus nigricollis*). Of the total reported mammals, 11 species are legally protected under different schedules of the Indian Wildlife (Protection) Act, 1972 (Table 1).

Avian diversity

Uttarakhand is home to 14 important Bird Areas (Islam and Rahmani, 2004) that are important and priority sites for conservation (Mohan and Sondhi, 2017). BWLS is rich in avian diversity, it has been declared as an important bird area IBA (A3) by BirdLife International. The sanctuary harbors 173 species of birds under 12 orders belonging to 45 families (Table 2) and some of the common species of birds reported in the sanctuary named as, Koklass Pheasants (*Pucrasia macrolopha*), Kaleej Phaesants (*Lophura leucomelana*), Hill Partridges (*Arborophilla torqueola*), Great Barbets (*Megalaima virens*), Himalayan Griffons (*Gyps himalayensis*), Black Francolins (*Fracolinus francolinus*), Mountain Hawk Eagle (*Nisaetus nipalensis)*, Lammergeiers *(Gypaetus barbatus)*,White-throated Tit (*Aegithalous niveogularis*), Red -billed Blue Magpies (*Urocissa erythrorhyncha*) and Yellow-Billed Magpies (*Urocissa flavirostris*). Total number of species of bird's orders and their families compiled from the BWLS is presented in Figure 2. As per the IUCN Red List of Threatened Species, five species are near threatened, one species is vulnerable, one species is endangered, one species is critically endangered and 161 species are least concerned (Table 2).

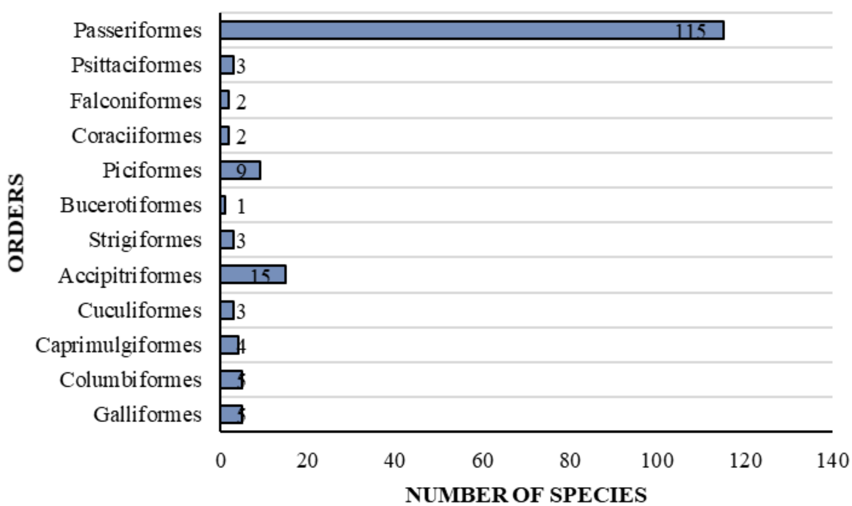

Figure 2. Number of species of bird's orders and their families reported from the BWLS.

Table 2. Avian faunal species composition of Binsar Wildlife Sanctuary.

ORDER/Family	Common Name	Scientific Name	Status: IUCN
ACCIPITRIFORMES / Accipitridae	Lammergeier	*Gypaetus barbatus*	NT
	Egyptian Vulture	*Neophron percnopterus*	E
	Crested Serpent Eagle	*Spilornis cheela*	LC
	Red-headed Vulture	*Sarcogyps calvus*	CE
	Himalayan Vulture	*Gyps himalayensis*	NT
	Mountain Hawk Eagle	*Nisaetus nipalensis*	LC
	Black Eagle	*Ictinaetus malayensis*	LC
	Tawny Eagle	*Aquila rapax*	V
	Golden Eagle	*Aquila chrysaetos*	LC
	Bonelli's Eagle	*Aquila fasciata*	LC
	Shikra	*Accipiter badius*	LC
	Eurasian Sparrowhawk	*Accipiter nisus*	LC
	Lesser Fish Eagle	*Icthyophaga humilis*	NT
	Black Kite	*Milvus migrans*	LC
	Upland Buzzard	*Buteo hemilasius*	LC
BUCEROTIFORMES/ Upupidae	Common Hoopoe	*Upupa epops*	LC
CAPRIMULGI-FORMES / Caprimulgidae	Grey Nightjar	*Caprimulgus indicus*	LC
	Large-tailed Nightjar	*Caprimulgus macrurus*	LC
CAPRIMULGI-FORMES/ Apodidae	White-throated Needletail	*Hirundapus caudacutus*	LC
	Fork-tailed Swift	*Apus pacificus*	LC
COLUMBIFORMES/ Columbidae	Wood Pigeon	*Columba palumbus*	LC
	Oriental Turtle Dove	*Streptopelia orientalis*	LC
	Spotted-necked Dove	*Stigmatopelia chinensis*	LC
	Yellow-legged Green Pigeon	*Treron phoenicopterus*	LC
	Wedge-tailed Green Pigeon	*Treron sphenurus*	LC
CORACIIFORMES/ Alcedinidae	Common Kingfisher	*Alcedo atthis*	LC
	White-throated Kingfisher	*Halcyon smyrnensis*	LC
CUCULIFORMES/ Cuculidae	Large Hawk Cuckoo	*Hierococcyx sparverioides*	LC
	Indian Cuckoo	*Cuculus micropterus*	LC
	Common Cuckoo	*Cuculus canorus*	LC
FALCONIFORMES/ Falconidae	Common Kestrel	*Falco tinnunculus*	LC
	Peregrine Falcon	*Falco peregrinus*	LC
GALLIFORMES/ Phasianidae	Common Hill Partridge	*Arborophila torqueola*	LC
	Chukar Partridge	*Alectoris chukar*	LC
	Black Francolin	*Francolinus francolinus*	LC
	Kalij Pheasant	*Lophura leucomelanos*	LC
	Koklass Pheasant	*Pucrasia macrolopha*	LC
PASSERIFORMES/ Campephagidae	Long-tailed Minivet	*Pericrocotus ethologus*	LC
	Black-winged Cuckooshrike	*Lalage melaschistos*	LC

Table 2. *Continued...*

ORDER/Family	Common Name	Scientific Name	Status: IUCN
PASSERIFORMES/ Vireonidae	Himalayan Shrike-babbler	*Pteruthius ripleyi*	LC
PASSERIFORMES/ Oriolidae	Maroon Oriole	*Oriolus traillii*	LC
	Indian Golden Oriole	*Oriolus kundoo*	LC
	Black-naped Oriole	*Oriolus chinensis*	LC
PASSERIFORMES/ Vangidae	Bar-winged Flycatcher-shrike	*Hemipus picatus*	LC
PASSERIFORMES/ Dicruridae	Black Drongo	*Dicrurus macrocercus*	LC
	Ashy Drongo	*Dicrurus leucophaeus*	LC
	Bronzed Drongo	*Dicrurus aeneus*	LC
	Hair-crested Drongo	*Dicrurus hottentottus*	LC
PASSERIFORMES/ Rhipiduridae	White-throated Fantail	*Rhipidura albicollis*	LC
PASSERIFORMES/ Corvidae	Grey Treepie	*Dendrocitta formosae*	LC
	Red-billed Blue Magpie	*Urocissa erythroryncha*	LC
	Yellow-billed Magpie	*Urocissa flavirostris*	LC
	Eurasian Jay	*Garrulus glandarius*	LC
	Black-headed Jay	*Garrulus lanceolatus*	LC
	House Crow	*Corvus splendens*	LC
	Large-billed Crow	*Corvus macrorhynchos*	LC
PASSERIFORMES/ Dicaeidae	Fire breasted Flowerpecker	*Dicaeum ignipectus*	LC
PASSERIFORMES/ Nectariniidae	Black-throated Sunbird	*Aethopyga saturata*	LC
	Green-tailed Sunbird	*Aethopyga nipalensis*	LC
PASSERIFORMES/ Prunellidae	Alpine Accentor	*Prunella collaris*	LC
	Robin Accentor	*Prunella rubeculoides*	LC
	Rufous-breasted Accentor	*Prunella strophiata*	LC
PASSERIFORMES/ Estrildidae	Indian Silverbill	*Euodice malabarica*	LC
	Scaly-breasted Munia	*Lonchura punctulata*	LC
PASSERIFORMES/ Passeridae	House Sparrow	*Passer domesticus*	LC
	Russet Sparrow	*Passer cinnamomeus*	LC
	Eurasian Tree Sparrow	*Passer montanus*	LC
PASSERIFORMES/ Motacillidae	Paddyfield Pipit	*Anthus rufulus*	LC
	Grey Wagtail	*Motacilla cinerea*	LC
	White Wagtail	*Motacilla alba*	LC

Table 2. *Continued...*

ORDER/Family	Common Name	Scientific Name	Status: IUCN
PASSERIFORMES/ Fringillidae	Blyth's Rosefinch	*Carpodacus grandis*	NE
	Pink-browed Rosefinch	*Carpodacus rodochroa*	LC
	Vinaceous Rosefinch	*Carpodacus vinaceus*	LC
	Common Rosefinch	*Carpodacus erythrinus*	LC
	Brown Bullfinch	*Pyrrhula nipalensis*	LC
	Orange Bullfinch	*Pyrrhula aurantiaca*	LC
	Red-headed Bullfinch	*Pyrrhula erythrocephala*	LC
	Plain Mountain Finch	*Leucosticte nemoricola*	LC
	Yellow-breasted Greenfinch	*Chloris spinoides*	LC
PASSERIFORMES/ Emberizidae	Crested Bunting	*Melophus lathami*	LC
	Rock Bunting	*Emberiza cia*	LC
PASSERIFORMES/ Stenostiridae	Grey headed canary flycatcher	*Culicicapa ceylonensis*	LC
PASSERIFORMES/ Paridae	Fire-capped Tit	*Cephalopyrus flammiceps*	LC
	Coal Tit	*Periparus ater*	LC
	Rufous-naped Tit	*Periparus rufonuchalis*	LC
	Green-backed Tit	*Parus monticolus*	LC
	Cinereous Tit	*Parus cinereus*	NE
	Spot-winged Tit	*Parus melanolophus*	NE
	Black-lored Tit	*Machlolophus xanthogenys*	LC
	Yellow-cheeked Tit	*Machlolophus spilonotus*	LC
PASSERIFORMES/ Pnoepygidae	Scaly breasted Wren Babbler	*Pnoepyga albiventer*	LC
PASSERIFORMES/ Hirundinidae	Nepal House Martin	*Delichon nipalense*	LC
	Barn Swallow	*Hirundo rustica*	LC
PASSERIFORMES/ Pycnonotidae	Black Bulbul	*Hypsipetes leucocephalus*	LC
	Himalayan Bulbul	*Pycnonotus leucogenis*	LC
	Red-vented Bulbul	*Pycnonotus cafer*	LC
PASSERIFORMES/ Phylloscopidae	Buff-barred Warbler	*Phylloscopus pulcher*	LC
	Ashy-throated Warbler	*Phylloscopus maculipennis*	LC
	Plain Leaf Warbler	*Phylloscopus neglectus*	LC
	Hume's Warbler	*Phylloscopus humei*	LC
	Tickell's Leaf Warbler	*Phylloscopus affinis*	LC
	Greenish Leaf Warbler	*Phylloscopus trochiloides*	LC
	Large-billed Leaf Warbler	*Phylloscopus magnirostris*	LC
	Yellow-vented Leaf Warbler	*Phylloscopus cantator*	LC
	Grey-hooded Leaf Warbler	*Phylloscopus/ xanthoschistos*	LC
PASSERIFORMES/ Scotocercidae	Black-faced Warbler	*Abroscopus schisticeps*	LC
	Aberrant Bush Warbler	*Horornis flavolivaceus*	LC
PASSERIFORMES/ Aegithalidae	Black-throated Tit	*Aegithalos concinnus*	LC
	White-throated Tit	*Aegithalos niveogularis*	LC
PASSERIFORMES/ Zosteropidae	Whiskered Yuhina	*Yuhina flavicollis*	LC
	Oriental White-eye	*Zosterops palpebrosus*	LC

Table 2. *Continued...*

ORDER/Family	Common Name	Scientific Name	Status: IUCN
PASSERIFORMES/ Leiothrichidae	Striated Laughing thrush	*Grammatoptila striata*	LC
	White-throated Laughing-thrush	*Garrulax albogularis*	LC
	Streaked Laughing-thrush	*Trochalopteron lineatum*	LC
	Chestnut-crowned Laughing-thrush	*Trochalopteron erythrocephalum*	LC
	Rufous Sibia	*Heterophasia capistrata*	LC
	Chestnut-tailed Minla	*Chrysominla strigula*	LC
PASSERIFORMES/ Regulidae	Goldcrest	*Regulus regulus*	LC
PASSERIFORMES/ Certhiidae	Bar-tailed Treecreeper	*Certhia himalayana*	LC
	Eurasian Treecreeper	*Certhia familiaris*	LC
	Hodgson's Treecreeper	*Certhia hodgsoni*	LC
PASSERIFORMES/ Sittidae	White-tailed Nuthatch	*Sitta himalayensis*	LC
PASSERIFORMES/ Sturnidae	Common Myna	*Acridotheres tristis*	LC
	Jungle Myna	*Acridotheres fuscus*	LC
	Hill Myna	*Gracula religiosa*	LC
PASSERIFORMES/ Muscicapidae	Oriental Magpie Robin	*Copsychus saularis*	LC
	Dark-sided Flycatcher	*Muscicapa sibirica*	LC
	Rusty-tailed Flycatcher	*Muscicapa ruficauda*	LC
	Rufous-bellied Niltava	*Niltava sundara*	LC
	Asian Verditer Flycatcher	*Eumyias thalassinus*	LC
	Indian Blue Robin	*Larvivora brunnea*	LC
	Little Forktail	*Enicurus scouleri*	LC
	Spotted Forktail	*Enicurus maculatus*	LC
	Blue-fronted Robin	*Cinclidium frontale*	LC
	Blue Wshistling Thrush	*Myophonus caeruleus*	LC
	Himalayan Bluetail	*Tarsiger rufilatus*	LC
	Ultramarine Flycatcher	*Ficedula superciliaris*	LC
	Little Psied Flycatcher	*Ficedula westermanni*	LC
	White-capped Water Redstart	*Chaimarrornis leucocephalus*	LC
	Blue-fronted Redstart	*Phoenicurus frontalis*	LC
	Blue-capped Redstart	*Phoenicurus coeruleocephala*	LC
	Black Redstart	*Phoenicurus ochruros*	LC
	Chestnut-bellied Rock Thrush	*Monticola rufiventris*	LC
	Blue Rock Thrush	*Monticola solitarius*	LC
	Pied Bush Chat	*Saxicola caprata*	LC
	Desert Wheatear	*Oenanthe deserti*	LC

Table 2. *Continued...*

ORDER/Family	Common Name	Scientific Name	Status: IUCN
PASSERIFORMES/ Turdidae	Long-tailed Thrush	*Zoothera dixoni*	LC
	Plain-backed Thrush	*Zoothera mollissima*	LC
	Long-billed Thrush	*Zoothera monticola*	LC
	Scaly Thrush	*Zoothera dauma*	LC
	Mistle Thrush	*Turdus viscivorus*	LC
	Grey-winged Blackbird	*Turdus boulboul*	LC
	Tickell's Thrush	*Turdus unicolor*	LC
	White-collared Blackbird	*Turdus albocinctus*	LC
	Chestnut Thrush	*Turdus rubrocanus*	LC
	Red-throated Thrush	*Turdus ruficollis*	LC
PASSERIFORMES/ Troglodytidae	Winter Wren	*Troglodytes troglodytes*	LC
PICIFORMES/ Ramphastidae	Great Barbet	*Psilopogon virens*	LC
PICIFORMES/ Picidae	Black rumped Woodpecker	*Dinopium benghalense*	LC
	Greater Yellow naped Woodpecker	*Chrysophlegma flavinucha*	LC
	Lesser Yellow naped Woodpecker	*Picus chlorolophus*	LC
	Grey-headed Woodpecker	*Picus canus*	LC
	Scaly-bellied Woodpecker	*Picus squamatus*	LC
	Brown-fronted Woodpecker	*Dendrocopos auriceps*	LC
	Himalayan Woodpecker	*Dendrocopos himalayensis*	LC
	Rufous-bellied Woodpecker	*Dendrocopos hyperythrus*	LC
PSITTACIFORMES/ Psittaculidae	Slaty-headed Parakeet	*Psittacula himalayana*	LC
	Blossom-headed Parakeet	*Psittacula roseata*	NT
	Red-Breasted Parakeet	*Psittacula alexandri*	NT
	Plum-headed Parakeet	*Psittacula cyanocephala*	LC
STRIGIFORMES/ Strigidae	Collared Owlet	*Glaucidium brodiei*	LC
	Asian Barred Owlet	*Glaucidium cuculoides*	NE
	Brown Wood Owl	*Strix leptogrammica*	LC

(Abbreviations used: Status as per the IUCN Red List of Threatened Species, NT = Near Threatened, E = Endangered, CE = Critically Endangered, VU= Vulnerable, LC = Least Concerened and NE = Not Evaluated)

The charismatic wildlife species inhabiting Binsar is the leopard (*Panthera pardus*) and is the top predator here (Bhalla *et al*., 2015). Kala and Kothari (2013) reported nine species of mammals and birds each from the BWLS. Rawat *et al*. (2013) reported four species of mammals and two species of birds. Khan *et al*. (2000), Majila and Kala (2010) and Bhalla *et al*. (2015) reported 10 species of birds and mammals from the BWLS. BWLS is rich in avian diversity, it has been declared as an important bird area by BirdLife International with over 160 species. BWLS is an important Bird Area under the A3 Category of Biome 08 (BirdLife International, 2021). The sanctuary also harbors 166 species of birds

(Uttarakhand Forest Department, 2014). Mohan and Sondhi (2014, 2015, 2017) published three updated checklists of the birds of Uttarakhand listing 686, 693 and 710 species of birds. Bhalla *et al.* (2020) documented some previously recorded birds and mammal species and added a single species of Indian porcupine (*Hystrix indica*) to BWLS. Sultana and Khan (2000) studied the birds of oak forest in the Kumaun Himalaya and documented a total of 382 bird species from Kumaun Himalaya including species from Almora (182 birds), Nainital (81 birds), Pithoragarh (162 birds) districts respectively. Shahabuddin *et al.* (2017) documented 136 species of birds from banjoak- chirpine forest of Nainital and Almora Districts of Kumaon, Uttarakhand. In a more recent years, Lepage (2021) documented checklist of 165 species of birds belonging to 12 orders and 44 families in the Avibase, the word bird database of Binsar Wildlife Sanctuary, Almora.

Insect diversity

The sanctuary also harbors major group of insects including butterflies, moths, beetles, bees, grasshoppers, dragon flies, bugs and dipteran flies. A total of 121 species of insects belonging to 36 families and eight orders were reported from BWLS. Total number of species of different insect orders and their percent contribution to total number of species recorded from BWLS is presented in Figure 3. Order Lepidoptera was the most dominant order with 50 species and amounting to 41.32% of the total number of species of insects, followed by Coleoptera (25) amounting to 20.66%, Hymenoptera (14) amounting to 11.57%, Orthoptera (10) amounting to 8.26%, Odonata (8) amounting to 6.61%, Diptera (7) amounting to 5.79%, Hemiptera (6) amounting to 4.96% and Dictyoptera with a single species.

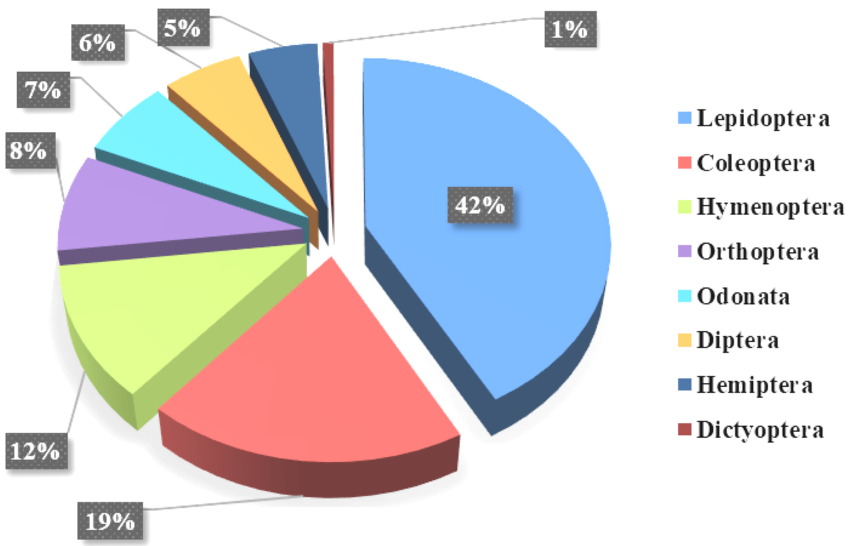

Figure 3. Total number of species of different insect orders and their percent contribution to total number of species recorded from BWLS.

Order Lepidoptera: Lepidoptera was the most dominant insect order in the sanctuary, represented by 50 species under eight families (Table 3). Five species namely *Neptis sankara* (under Schedule I), *Neptis zaida*, *Callerebia scanda* (under Schedule II), *Euploea core*, *Aporia agathon* (under Schedule IV) are legally protected under the Indian Wildlife (Protection) Act, 1972. On the basis of total number of species, Nymphalidae was the most dominant family of this order with 23 species followed by Pieridae (12), Lycaenidae (4), Papilionidae, Riodinidae (three each), Hesperiidae (2), Erebidae, Noctuidae and Sphingidae (one each), respectively. Status of species of Lepidopteran insects was assigned as Very Common (VC) when counted in large numbers of individuals, Common (C) when observed regularly, Uncommon (UC) when recorded occasionally and Rare (R) when recorded rarely (Table 3 and Figure 4).

Order Coleoptera: Coleoptera was the second most dominant insect order in the BWLS and represented 25 species under six families. Species composition of coleopteran insects of the BWLS has been shown in the Table 4. On the basis of the total number of species, Scarabaeidae was the most dominant family of this order with 12 species followed by Chrysomelidae (5), Coccinellidae, Dytiscidae, Meloidae (2 species each), Lagriidae and Tenebrionidae (one each), respectively.

Other minor insect orders: Table 5 shows the species composition of other minor group of insect orders reported from the BWLS. Hymenoptera was the third most dominant insect order in the sanctuary and belonging to 14 species under seven families. On the basis of the total number of species, Apidae was the most dominant family of this order with six species followed by Ichneumonidae, Scoliidae (two each), Pompilidae, Sphecidae, Vespidae and Xylocopidae (one each), respectively. Orthoptera was represented by only two families. Acrididae was the dominant family with eight species, while Tettigonidae was represented by two species.

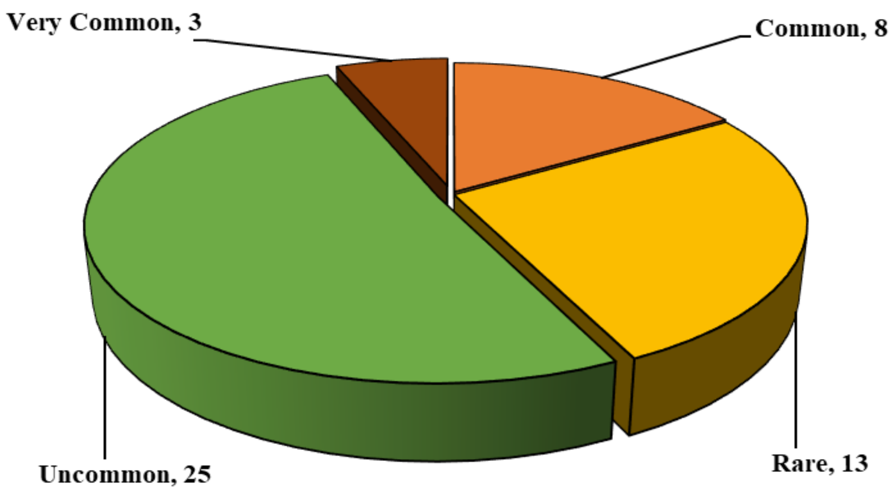

Figure 4. Status of species of Lepidopteran insects recorded from BWLS

Table 3. Species composition of Lepidopteran fauna of Binsar Wildlife Sanctuary.

Family	Common Name	Species Name	Local status
Nymphalidae	Yellow Coster	*Acraea issoria anamala* Kollar	R
	Indian Tortoiseshell	*Aglais cashmirensis* (Fruhstorfer)	VC
	Large Silverstripe	*Argynnis childreni* (Grey)	UC
	Indian Fritillary	*Argynnis hyperbius* Linnaeus	C
	Common Satyr	*Aulocera swaha* Kollar	R
	Great Satyr	*Aulocera padma* Kollar	R
	Ringed Argus	*Callerebia annada* (Moore)	R
	Pallid Argus	*Callerebia scanda* (Kollar)*	UC
	Plain Tiger	*Danaus chrysippus* (Linnaeus)	UC
	Common Crow	*Euploea core* (Cramer)*	UC
	Chocolate Pansy	*Junonia iphita* Cramer	C
	Orange Oakleaf	*Kallima inachus* Boisduval	UC
	Blue Admiral	*Kaniska canace* (Linnaeus)	R
	Common Wall	*Lasiommata schakra* (Kollar)	R
	Straight-Banded Treebrown	*Lethe verma* Kollar	UC
	Broad-Banded Sailer	*Neptis sankara* (Kollar)*	UC
	Pale Green Sailer	*Neptis zaida* Westwood*	R
	Tabby	*Pseudergolis wedah* (Kollar)	UC
	Common Leopard	*Phalanta phalantha* (Drury)	UC
	Western Courtier	*Sephisa dichroa* (Kollar)	UC
	Painted Lady	*Vanessa cardui* Linnaeus	UC
	Indian Red Admiral	*Vanessa indica* Herbst	VC
	Large Three-Ring	*Ypthima nareda nareda* (Kollar)	UC
Pieridae	Pioneer	*Belenois aurota* (Fabricius)	UC
	Common Emigrant	*Catopsilia pomona* Linnaeus	C
	Dark Clouded Yellow	*Colias fieldii* Menetries	C
	Small Grass Yellow	*Eurema brigitta rubella* Wallace	UC
	Common Grass Yellow	*Eurema hecabe* Linnaeus	C
	Spotless Grass Yellow	*Eurema laeta* Boisduval	UC
	Himalayan Brimstone	*Gonepteryx rhamni nepalensis* Linnaeus	C
	Great Blackvein	*Aporia agathon agathon** (Gray)	UC
	Great Blackvein	*Aporia agathon phryxe* (Boisduval)	R
	Large Cabbage White	*Pieris brassicae* Linnaeus	C
	Indian Cabbage White	*Pieris canidia indica* Evans	VC
	Bath White	*Pontia daplidice* (Linnaeus)	R
Lycaenidae	Sorrel Sapphire	*Heliophorus sena* Kollar	UC
	White-Bordered Copper	*Lycaena panava* (Kollar)	UC
	Red Pierrot	*Talicada nyseus* (Guerin-Meneville)	UC
	Pale Hedge Blue	*Udara dilectus* Moore	R

Table 3. *Continued...*

Family	Common Name	Species Name	Local status
Papilionidae	Common Windmill	*Byasa polyeuctes letincius* (Fruhstorfer)	UC
	Common Peacock	*Papilio bianor polyctor* Boisduval	UC
	Common Mormon	*Papilio polytes* Linnaeus	UC
Riodindae	Common Punch	*Dodona durga durga* (Kollar)	UC
	Tailed Punch	*Dodona eugenes* Bates	R
	Mixed Punch	*Dodona ouida* Hewitson	UC
Hesperiidae	Himalayan Darter	*Ochlodes brahma* Moore	R
	Evan's Snow Flat	*Tagiades cohaerens Cynthia* Evans	R
Erebidae	-	*Calpe ophideroides* Guenee	R
	Handmaiden moth	*Syntomoides imaon* Cramer	C
Sphingidae	Hawkmoth	*Macroglossum* sp.	UC

(Abbreviations used: VC = Very Common, C = Common, UC = Uncommon, R = Rare and * indicates legally protected species under the Indian Wildlife (Protection) Act, 1972)

Odonata was represented by eight species under four families. On the basis of the total number of species, Libellullidae was the most dominant family of this order with five species followed by Aeschnidae, Euphaeidae and Synlestidae (one each), respectively. Diptera was represented by seven species under four families. Tabanidae was the most dominant family of this order with three species followed by Asilidae (2), Syrphidae and Tipulidae (one each), respectively. Hemiptera was represented by six species under three families. On the basis of the total number of species, Pentatomidae was the most dominant family of this order with three species followed by Coreidae (2) and Lygaeidae (1). Order Dictyoptera was represented by single family Mantidae with species *Deiphobe infuscate* Saussure. Figure 5 shows some images of insects recorded in BWLS.

Acraea issoria *Aglais cashmirensis* *Aulocera swaha* *Orthetrum taeniolatum* *Orthetrum glaucum* *Orthetrum pruinosum*

Euploea core *Lasiommata schakra* *Aporia agathon* *Apis cerana* *Bombus sp.* *Coccinella septumpunctata*

Figure 5. Examples of insect fauna reported from BWLS

Table 4. Species composition of coleopteran insects of Binsar Wildlife Sanctuary.

ORDER: COLEOPTERA	
Family: Scarabaeidae	*Meristata sexmaculata* (Kollar & Redtenbacher)
Anomala lineatopennis Blanchard	*Merista tatrifasciata* Hope
Anomala sp.	*Mimastra* sp.
Gymnopleurus subtilis Walker	**Family: Coccinellidae**
Jumnos roylei Hope	*Coccinella septumpunctata* Linnaeus
Lachnosterna cavifrons Brenske	*Haluzia sanscrieta* Muls.
Lytta limbata Redtenbacher	**Family: Meloidae**
Onthophagus gagates Hope	*Mylabris cichorii* Linnaeus
O. rubricollis Hope	*Mylabris* sp.
Protaetia neglacta Hope	**Family: Lagriidae**
P. pretiosa Nonfried	*Cerogria nepalensis* Hope
Pseudolucanus cantor Hope	**Family: Tenebrionidae**
Scarites sulcatus Olivier	*Cistelomorpha* sp.
Family: Chrysomelidae	**Family: Dytiscidae**
Altica himensis Shukla	*Agabus amoenus sinuaticollis* Regimbart
Gallerucida rutilans Hope	*Agabus biguttatus* (Oliver)

Table 5. Species composition of minor groups of insect orders of Binsar Wildlife Sanctuary.

ORDER: HYMENOPTERA	**ORDER: ODONATA**
Family: Apidae	**Family: Libellullidae**
Anthophora confuse Smith	*Crocothemis servilia servilia* (Drury)
Apis cerana Fabricius	*Orthetrum sabina sabina* (Drury)
Apis laboriosa Smith	*O. glaucum* Brauer
Bombus sp.	*O. pruinosum neglectum* (Rambur)
Bremus sp.	*O. taeniolatum* (Schneider)
Crocisa ramose Lepeletier	**Family: Aeschnidae**
Family: Ichneumonidae	*Anax immaculiforns* Rambur
Ichneumon sp.	**Family: Euphaeidae**
Ophion sp.	*Bayadera indica* (Selys)
Family: Scoliidae	**Family: Synlestidae**
Compsomeris asiatica himalaya Bar.	*Megalestes major* Selys
Scolia venusta Smith	**ORDER: DIPTERA**
Family: Pompilidae	**Family: Tabanidae**
Salius flavus Fabricius	*Pangonia longirostris* Hardwicke
Family: Sphecidae	*Philoliche* sp.
Ammophila punctata Smith	*Tabanus orientis* Walker
Family: Vespidae	**Family: Asilidae**
Vespa sp.	*Philodious javanus* Wied.
Family: Xylocopidae	*Stenopogano ldroydi* Josephs & Pauri
Xylocopa fenestrate Fabricius	**Family: Syrphidae**

Table 5. *Continued...*

ORDER: ORTHOPTERA	*Syrphus fulvifacies* Brunetti
Family: Acrididae	Family: Tipulidae
Chorthippus almoranus Uvarov	*Tipula himalayensis* Brunetti
Gastrimargus transversus Thunberg	**ORDER: HEMIPTERA**
Heteropternis respondence (Walker)	**Family: Pentatomidae**
Paraconophyma scabra Walker	*Erthesina fullo* Thunberg
Patanga japonica (Bolivar)	*Dalpada* sp.
Pternoscirta cinctifemur Walker	*Nezara viridula* Linnaeus
Spathosternum p. prasiniferum (Walker)	**Family: Coreidae**
Xenocatantops karnyi Kirby	*Cletus punctulatus* Westwood
Family: Tettigonidae	*Ochrochira albiditarsis* Westwood
Himertula kinneri Uvarov	**Family: Lygaeidae**
Letana linearis (Walker)	*Lygaeus equestris* Linnaeus

BWLS harbors major two groups of insects i.e. butterflies and beetles and minor group of insects including bees, bumble-bees, carpenter bees, dragon flies, bugs and dipteran flies. In comparison, Ilyas (1998) documented two species of butterflies, Mixed Punch (*Dodona ouida* Hewitson) and Great Satyr (*Aulocera padma* Kollar) from the BWLS. In the recent years, Ghosh *et al.* (2011) and Ghosh *et al.* (2018) reported two species of aquatic beetles belonging to family Dytiscidae from the BWLS. Arya *et al.* (2016a) studied the distribution and diversity of beetles (Insecta: Coleoptera) in different elevational zones of BWLS, Almora, Uttarkhand, India and reported 23 species of beetles from 18 genera and six families. Arya *et al.* (2017) studied the population ecology and bioenergetics of *Chorthippus almoranus* Uvarov (Orthoptera: Acrididae) of the BWLS. Tamta (2017) recorded 115 species of insects belonging to eight orders from different locations of BWLS. Arya *et al.* (2018a) reported 53 species of anthophilous insects belonging to 18 families under four orders facilitating the pollination process in the entire area of the BWLS. Arya *et al.* (2018b) studied the bio-spectrum of different groups of insect orders and reported a total of 115 species of insects belonging to eight orders was sorted into four categories based on their major feeding habits viz., herbivorous, omnivorous, predators and saprophagous in the BWLS, Western Himalayas. In a more recent study, Arya *et al.* (2020) studied the diversity of butterflies (Lepidoptera: Papilionoidea) in a temperate forest ecosystem in the BWLS and reported 46 species and 35 genera under six families

Conclusion

BWLS is a low profiled protected area in terms of adopted biodiversity conservation and management strategies, and it is still unexplored or under-explored in relation to faunal diversity. The provided comprehensive checklist on faunal diversity chiefly mammals, Aves and different groups of insects is intended to serve as a reliable biodiversity data source for biological studies and will be helpful in biodiversity conservation and management plans as well as for monitoring faunistic changes which might occur as we move further deeper towards the Anthropocene in the 21st century.

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Chapter
[14]

Avifaunal diversity and conservation status of Okhla Bird Sanctuary, Noida, Uttar Pradesh, India

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Abstract

Okhla Bird Sanctuary, subside in the Gangetic plains falls in the semi-arid region. The sanctuary consists of a deep-water area, reed bed area, ponds, and shallow vegetated area that supports rich habitat for water and terrestrial birds. It is known for the occurrence of large congregations of winter migratory birds including some rare and endangered species. Present chapter is based on the published records and the observations carried by authors during 2018-19. Total 302 species have been reported so far. Four critically endangered species viz; White-rumped Vulture (*Gyps bengalensis*), Indian Vulture (*Gyps indicus*), Baer's Pochard (*Aythya baeri*), and Sociable Lapwing (*Vanellus gregarious*) have been reported from this area. Apart from this, three endangered species, nine vulnerable species, and seventeen near threatened species occur in this area. Based on the field observations and earlier discussion with the officials of the sanctuary, it has been observed that during the past one and half decades the population and species density of avifauna is decreased and some of the species which were frequently seen, are becoming rare. The wetland is facing conservation problems owing to anthropogenic pressure and water pollution. Thus, in the catchment area and surroundings of water bodies, dumping of wastes (such as garbage, sewages, food wastes, and polyethylene bags) should be banned and stopped by law enforcement.

Keywords Avifauna, Conservation issue, Diversity, Okhla Bird Sanctuary, Wetland

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Introduction

Okhla Bird Sanctuary, subside in the Gangetic plains falls in the semi-arid region (Jha and McKinley, 2015). It is located in the catchment area of river Yamuna, under south Delhi, and plays an important role as a breeding and/or feeding site for the water birds. According to an estimation, around 14,000 to 20,000 water birds have been recorded during winters (Urfi, 2003). The prominent feature of this site is the large-sized (about 4 km^2) lake which is formed after the creation of a barrage on the river in 1986. The area around Okhla circle, the river Yamuna and the marshland associated with it, are the preferred birding sites. Three hundred and twenty-four avian species have been recorded as per the forest department, Utter Pradesh. According to long-term study carried out by Urfi (2003), a total of 302 species of birds have been reported from the wetland. This sanctuary is one among the several ornithologically important sites along the river Yamuna (Ganguli, 1975).
The sanctuary consists of a deep-water area, reed bed area, ponds, and shallow vegetated area that supports rich habitat for water and terrestrial birds. The aquatic vegetation of this stretch is diverse. Reed beds that are abundant in the marshy areas are *Typha angustata* and *Phragmites maxima*. The submerged vegetation includes *Vallisneria spiralis*, *Hydrilla verticillata*, *Potamogeton pectinatus*, and *Najas* species. Water hyacinth such as *Eichhornia crassipes*, *Salvinia molesta* and *Alternanthera philoxeriodes* are found in river and form a dense mat over the water body. Trees and bushes *i.e., Tamarix dioica, Prosopis spp,* and *Ficus* species occur along with *Ipomoea fistulos* (Gopal and Shah, 1993). Recent updated information is lacking on the avifauna of Okhla Bird Sanctuary, so preparation of a checklist with updates was, thus, considered necessary for further conservation management of wetland.

Description of the study area

Okhla Bird Sanctuary (28^{o}33’56.3” N and 77^{o}18’56.6” E) is roughly 4 km^2 in size and situated on the entrance of Noida, in Gautam Buddh Nagar district, Uttar Pradesh. It is situated on the point where river Yamuna enters the state of UP leaving the territory of Delhi (Urfi, 2003). The wetland was declared a Wildlife Sanctuary for Birds on 8 May 1990 by the Govt. of Uttar Pradesh. It has an area of 400 ha with open water covering around 273 ha, reed and sand beds covering 97 ha, and roads and bunds comprising the remaining 30 ha area. The area consists of a vast alluvial plain with a gentle south-eastern slope. It is surrounded by roads and bounded by mesh-wirings and bunds (Manral *et al.* 2013). Wetland water body and reedbeds with waterbirds were shown in Figures (1-8).

Methods

Systematic observations were made on the avifauna of the Okhla Bird Sanctuary and few adjoining localities. Four days of field surveys were conducted from 24.02.2018 to 27.02.2018. Observations on birds were made every day from 6.30 am to 4.00 pm (with few exceptions), with the help of prismatic field binoculars (12x50 Bushnell). Identification of species was carried out with the help of field guides,

Figure 1. Map of India, pointing out the location of Okhla Bird Sanctuary.

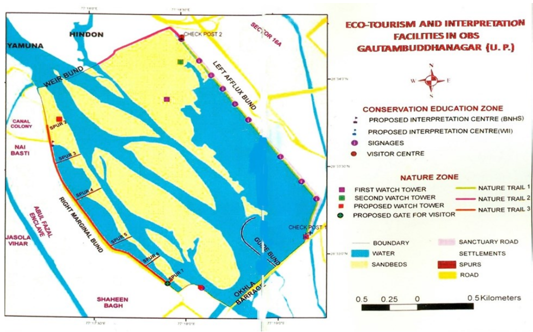

Figure 2. Map of the study area, Okhla Bird Sanctuary.

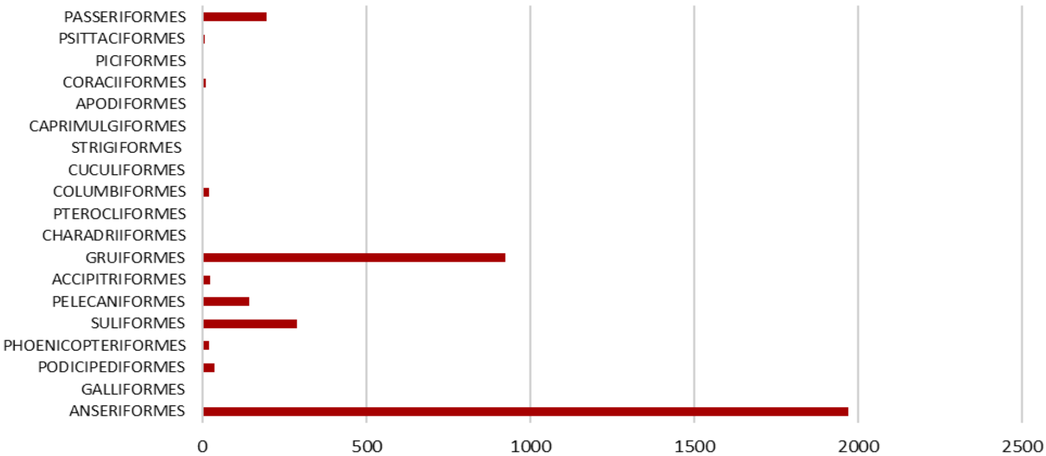

Figure 3. Showing the average number of individuals of different orders.

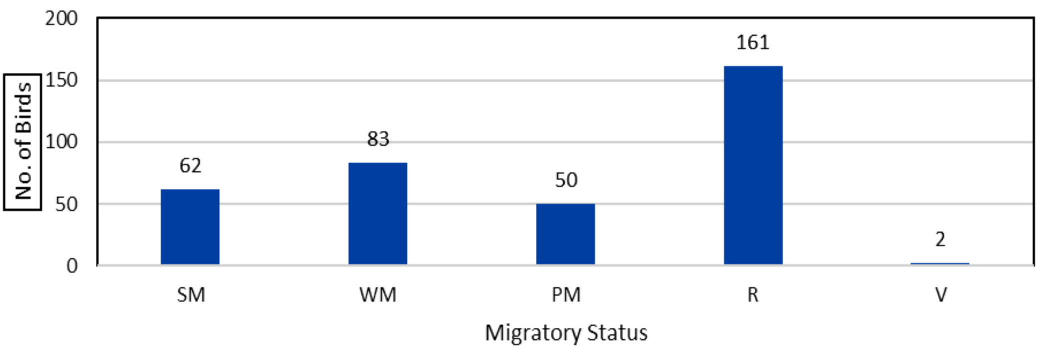

Figure 4. Migratory status of birds of Okhla Bird Sanctuary.

Figure 5. Landscape of Okhla Bird Sanctuary.

Figure 6. Landscape of Okhla Bird Sanctuary is showing urbanization in background.

Figure 7. Gadwall (*Mareca strepera*) and Northern Shoveler (*Spatula clypeata*) in flight.

Figure 8. Grey-headed Swamphen (*Porphyrio polio-cephalus*) are common at Okhla Bird Sanctuary.

Birds of the Indian Subcontinent by (Grimmett *et al*., 2003) and Birds of India (Grewal *et al*., 2016). The taxonomic order and nomenclature followed by Clements v 2018, updated in 2018 (Clements *et al*., 2018). 'Birds of South Asia: The Ripley Guide' (Rasmussen and Anderton, 2005) and 'Birds of India' (Kazmierczak and Perlo, 2009) were also considered to infer the occurrence of the species.

Conservation status

Based on direct sightings and published records, total 302 species of birds belonging to 70 families and 19 orders have been enlisted from the sanctuary, besides a few species remained unidentified due to inadequate observations (E-suppl. Resource 1). The most dominant order was Anseriformes followed by Gruciformes, Passeriformes, and Suliformes (Figure 3). The resident avian species are found in more numbers than the winter migrants followed by summer migrants, passage migrants, and vagarant

(Figure 4). This proves that the sanctuary plays a vital role for the resident birds of Delhi. Analysis of the data revealed, that the sanctuary supports the occurrence of four critically endangered species *viz*; White-rumped Vulture, Indian Vulture, Baer's Pochard and Sociable Lapwing and three endangered species *i.e.,* Greater Adjutant, Egyptian Vulture and Black-bellied Tern. Nine vulnerable species, namely Common Pochard, Sarus Crane, Woolly-necked Stork, Indian Skimmer, Pallas's Fish Eagle, Greater-Spotted Eagle, Lesser Adjutant, Bristled Grassbird and Finn's Weaver have been reported. Sixteen near threatened species such as Falcated Duck, Ferruginous Pochard, Black-necked Stork, Painted Stork, Darter, Grey-headed Fish Eagle, Black-headed Ibis, Cinereous Vulture, Great Thick Knee, River Lapwing, Eurasian Curlew, Black-tailed Godwit, River Tern, European Roller, Laggar Falcon and Alexandrine Parakeet were also reported. Three vulnerable and six near-threatened species were reported (Urfi, 2003). The numbers are now increased due to the change in the IUCN status of some species. During last one and half decades, it has been observed that the species which were endangered, many of them are now in IUCN critically endangered list, followed by species which were near threatened, several of them are now in vulnerable list. During past, the species which were commonly seen in the sanctuary area, are becoming rare. Taking this under consideration, necessary measures for the conservation of this wetland should be adopted.

Conservation Issues

Based on the field observations and earlier discussion with the officials of the sanctuary, it has been observed that during the past one and half decades the population and species density of avifauna is decreased and some of the species which were frequently seen, are becoming rare. Some of the major threats observed in the sanctuary are as listed below:

Pollution: Wetlands are the most complex and fragile ecosystems and do not have a self-cleaning ability and thus readily accumulate pollution (Jyoti and Hemant, 2003). Dispose of water bottles, plastic wrappers, and bags have been observed near the banks of the wetland. After discussing with the officials of the sanctuary, it was found that it was mostly disposed of by visitors. The sanctuary is becoming an excursion site for the people of Delhi. Knowingly, it has been observed that the people living nearby wetland are seen dumping wastes inside the sanctuary area thus making the water and surroundings more polluted.

Urbanization: Okhla bird sanctuary is rapidly becoming an island in a concrete jungle (Urfi, 2003). Over the past few decades, due to the urbanization, the habitats of wintering birds are shrinking and there has been a considerable loss of the remaining open fields and semi-natural marshes area around the Yamuna in Delhi. The water birds at Okhla are dependent upon the enclosed area, especially the agricultural fields, grassy patches, and marshy areas around the barrage for feeding. Their habitats are disappearing as more areas around the barrage are building up and so it is important to take concern about the surrounding sanctuary land to preserve the habitats of birds (Urfi, 1995).

Draining of sewage waste: Okhla stretch becomes the highest polluted stretch because of the discharge of about 18 drainage sewage including the large Najafgarh drain which discharges about 320.000

kilolitres of untreated sewage daily into the river, carrying a high concentration of pesticides and heavy metals (Anon, 1993).

Anthropogenic activities: Several anthropogenic activities like fishing and grazing of cattle (small herds) are seen in the wetland area, which not only affects the habitat, also disturbs the avifauna of the sanctuary. The wetland soils can directly reduce herbs/ grasses on the site through intensive grazing by livestock and it can also reduce the ability of the land to produce vegetation through soil compaction and long-term changes in soil structure (Adams and Akhtar, 1994).

Conclusion

In conclusion, after studying the past scenario and surveying the current status of Okhla Bird Sanctuary, we found that over the years, the wetland water gets polluted. Besides this, urbanization around the sanctuary and anthropogenic activities inside the sanctuary were increased by many folds. Present study revealed that the number of endangered and threatened birds are increased, due to species status update as per IUCN. Rehabilitation programmes are needed in order to sustain the ecological health and water quality of wetland, as most of the wetlands in the UP are slowly turning into reed-beds/ barren lands. In the catchment area and surroundings of water bodies, dumping of wastes (such as garbage, sewages, food wastes, and polyethylene bags) should be banned and stopped by law enforcement.

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E-Supplementary resource

Online version of this book chapter contains additional supplementary resource/data which can be accessed at: https://www.aesacademy.org/book/biological-diversity-current-status-and-conservation-policies.

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Chapter [15]

Role of earthworm biodiversity in soil fertility and crop productivity improvement

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Abstract

The earthworms are the biological indicator of the soil ecosystem as they indicate the health and fertility of the soil for proper cropping. In the soil for proper aeration, rich nutrient contents earthworms are very essential organisms. They enhance the nutrients contents, increase water holding capacity, and improve microbial activity in the soil. All over the world approximately 3627 species of earthworms are there. Earthworms are of two type's micrdrilli and megadrilli, in microdrilli group about 280 species, and the rest all are under megadrilli. Megadrilli group earthworms are soil living earthworms, they are grouped under three subgroups epigeic, endogeic, and anecic. Earthworms work for formers day- night without any labor charge and make the soil more nutritious and more aerated that helps in crop production. The major problem nowadays is to be recycled the organic waste into humus like products. For crop production enhancement organic manure is a better option instead of chemical fertilizer. Earthworms decompose the organic waste into organic manure. By the use of vermi techniques (use of earthworms and organic waste) in the presence of oxygen organic waste turns into manure. The diversity and number of the earthworms in the soil change the soil texture and improve nutrient contents.

Keywords Biodiversity, Earthworms, Soil, Vermicompost, Waste recycling

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Introduction

The burrowing habit of earthworms makes the soil more porous and creates a new way to proper aeration in the soil. Earthworms feed decaying organic waste and soil and excrete approximately 60 to 80% of their feed (Sinha *et al*., 2002). Their role in soil fertility is very crucial as they make soil more air convener and discharge nutrients into the soil present in their feces. Earthworms are the "intestine of the earth" said by Aristotle they decompose the organic matter like plants leafs decaying fruits and soil also (Bhadauria and Sexana, 2010). The soil fertility increases with an increase in the nutrients, proper aeration, and water holding capacity, along with these factors microbial activities also have a huge impact on the soil. The fertility of the soil is directly proportional to the crop improvement (Rochester *et al*., 2001). Earthworms are delivering natural services to human beings from ancient times to nowadays by providing worm manure (vermicast) and vermiwash which positively affects soil fertility and crop improvement. Earthworms are the friends of the farmer they plough the field without any cost. Earthworms work for farmer's day-night and improve crop productivity by making their field more nutritive by converting the decaying organic matter into humus-like products. Earthworms are soil ecosystem modifiers as they are improving the soil nutrient profiles (Jones *et al*., 1994).

General description and origin of earthworms

Earthworms are soil worms that live in organic matter-rich soil. Earthworm feeds on surface decaying organic matter like plant leaf, fruit wastes, and other biodegradable wastes. They consume waste and convert it into humus-like products like vermicompost (manure). The ancestor of today's earthworms was originated approximately 600 million years ago and from the days of origin, they enhance the soil profile by making the soil more porous and secreting their mucus into the soil (Sinha, 2009). The first earthworm named by Linnaeus in 1758 that was *Lumbricus terrestris*. The next species of earthworm discovered was *Eisenia fetida* described by Savigny (1826) and Cuvier (1824). Earthworms are found over the globe except in snowy and very hot regions because earthworms are very temperature sensitive however they have diverse habitats where nutrient-rich organic matter easily available like the garden, paddy fields, and places rich in moisture contents nearly 55 to 60% (Gupta *et al*., 2016). The earthworms is long, with cylindrical elongated body, compressed at both the ends, the body of earthworms is covered with a soft thin pellicle. The pellicles of earthworms are transparent and temperature-sensitive.

Body divided metamerically into 80 to 100 segments. Earthworms are hermaphrodite mean male and female reproductive organs found in single organisms. Sexual maturity attains at the age of 6 weeks. When environmental conditions favorable a pair of earthworms can produce more than 100 cocoons in 6 weeks to 6 months (Ismail, 1997).

Systematics: Earthworms come under the phylum Annelida and belong to the group Oligochaeta. The

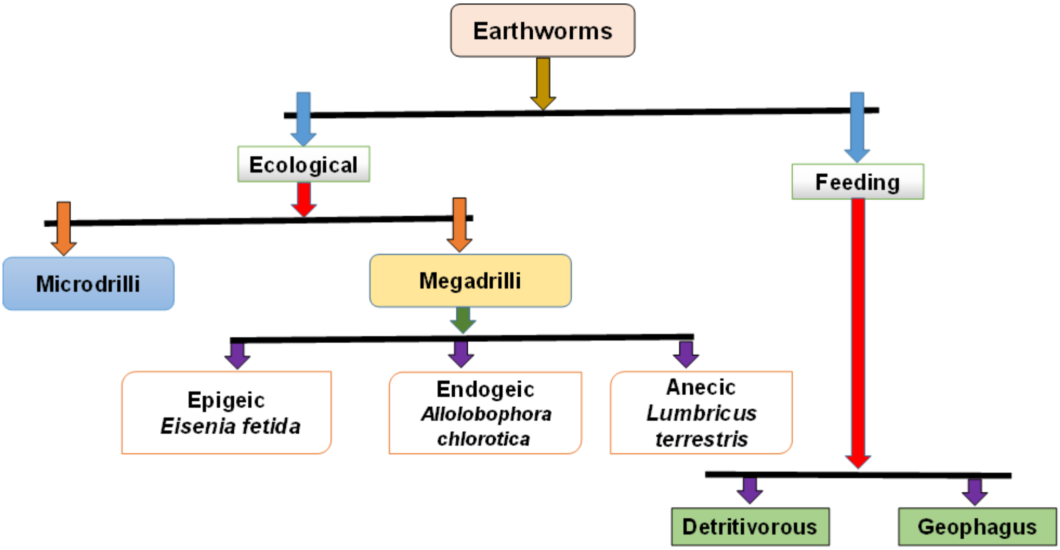

Figure 1. Systematic of earthworm distribution based on the ecological and feeding niche.

name earthworm is derived from the burrowing habit in the soil. In the world 3627 species of earthworm are present (Figure 1). Out of 3627 species, in India, 509 species are present which come under the 67 genera (Sinha *et al*., 2002).

Classification of earthworms based on their ecological adaptations

Based on the ecological adaptations firstly divided into two categories microdrilli and megadrilli. Out of total 3627 earthworm species, 280 are microdrilli, these are the aquatic species and the rest comes under species megadrilli. Further megadrilli can be classified into three subgroups depending on the inhabiting layer of the soil (Bouche, 1977) (Figure 2).

Epigeic earthworms (e.g. *Eisenia fetida*, *Eudrilus eugeniae*, *Perionyx excavatus* etc.): Epigeic earthworms are surface feeder detritivorous worms that feed on surface debris, decaying organic wastes like crop residues, decaying organic wastes, leaf litters, plant roots, and animal dung and convert them into vermicast. Due to the short lifespan fecundity rate is high and epigeic earthworms are reproduced in diverse habitat and harsh environments (Kozenko *et al*., 2020). *E. fetida* is the most suitable species for vermiculture over the globe. Epigeic earthworms are small in size, they are 1 to 18 cm in length (Xiao *et al*., 2011). Epigeic earthworms live in the upper soil layer and do not build burrows and as well as epigeic species of earthworms are not involved in organic and inorganic matter mixing. Feed decaying organic wastes.

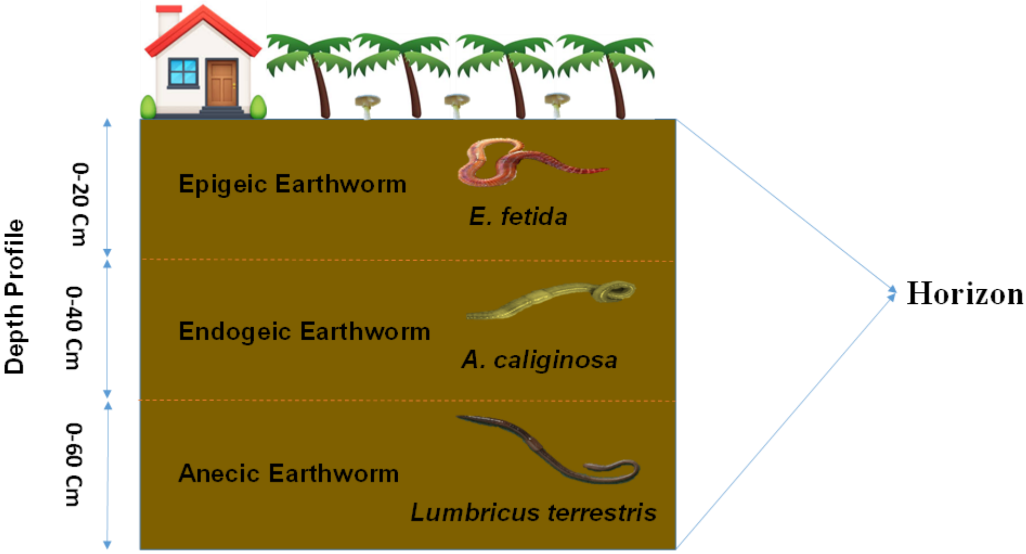

Figure 2. Habitat niche of the earthworms in the different layers of soil.

Endogeic species (e.g. *Allolobophora chlorotica, Apporectodea icterica, Murchieona muldali, Octolasion cyaneum* and *Octolasion lacteum*): Endogeic species of Earthworms are soil-inhabiting organisms they are not surface dwellers, live beneath the topsoil. The body size of the endogeic species is 2.5 to 30 cm in length. Endogeic species built horizontal burrow in the soil (Capoweiz *et al*., 2001; Perreault and Whalen, 2009). Endogeic species are the native species of Australian continents and are commonly found in New Zealand (Baker *et al*., 1999; Murchie and Gordon, 2013). The feeding matter of this species is soil which contains less organic matter as compared to surface layer feeding material. The soil texture is mainly changed by these species because endogeic earthworms feed more soil and less organic matter. These earthworms are not much suitable for vermicomposting but good for improving soil structure. The fecundity rate is low as compared to epigeic. Life span is relatively longer as compared to epigeic earthworms.

Anecic (e.g. *Aporrectodea longa, Aporrectodea nocturna, Lumbricus friendi and Lumbricus terrestris*): Anecic earthworms live in the deeper part of the soil in vertical burrows. They live in the soil at the depth of 3 meter. Anecic earthworms make vertical burrows and about 2 cm in diameter. They are the longest species category because anecic earthworm is about 3cm up to 20 cm long. Anecic earthworms help in the mixing of the organic nutrients in the soil and enhance the soil texture (paedogenesis). Anecic earthworms come out from their burrows at night and move to soil surface and where they eat decaying organic organic matter with some part of soil. This species of earthworm is not suitable for vermiculture because of the low decomposition efficacy of organic matter, low fecundity but anecic earthworm have a longer life span as compared to epigeic and endogeic earthworms (Bhadauria and Sexana, 2010).

Classification of earthworms' based on the feeding behavior

Based on the feeding habit earthworms can be classified as geophagous and detritivorous (Lee, 1985). Detritivorous feed on decaying organic waste like plant litters, decaying vegetables, fruits, and plant roots, cattle dungs at the soil surface and near the soil surface. They are humus former, convert the organic matter into the vermicompost. Epigeic is the detritivorous surface feeder of earthworms. Geophagus earthworm eat soil because they live beneath the soil in the horizontal burrow. Endogeic species are geophagus also called humus consumers because they eat soil with some part of organic waste.

Earthworms as bioindicator of soil fertility and health

The earthworms are the biological indicator of the soil ecosystem as they indicate the health and fertility of the soil for proper cropping (Pulleman *et al*., 2012). The number of earthworms in the soil determines the health of the soil and indicate the microorganisms like bacteria, fungi, viruses and other organisms in the soil, the high number of earthworm indicates the high biodiversity of the microorganisms in the soil (Lakzayi *et al*., 2015). A prominent microbial community is present in a rich organic matter area as many organisms like bacteria, fungi are present there for decomposition vermicompost is high in organic nutrients (Hedlund, 2002). Bacterial community and fungal hyphae in association with plant, enhance the soil productivity (Artursson *et al*., 2006; Nuccio *et al*., 2013). The high microbial population of bacteria, fungi, actinomycetes, and the higher enzymatic activity seen in the soil where the population of earthworm is high an area having higher earthworm diversity also have a higher microbial diversity that helps in the crop yield production without the use of chemical fertilizers (Haynes *et al*., 1999).

Role of earthworms in crop improvement

For a better and high yield of crop production and nutrients, rich organic production sustainable soil environment is necessary. Earthworms excrete various plant growth regulators in their mucus-like auxin and cytokinin (Krishnamoorthy and Vajranabhaiah, 1986). Earthworms play a key role in maintaining soil texture and balance soil ecosystem (Shuster *et al*., 2000). The major macrofauna of soil is earthworms they enhance the soil texture and nutrient content by secreting mucus in the soil, convert the organic biodegradable matter into nutrient-rich humus like manure (vermicast) (Sharma and Garg, 2018). Earthworms improve soil fertility by changing the biochemical and physical properties of soil. Earthworm excretion by-product vermicast is rich sources of various inorganic and organic nutrients (Edward *et al*., 1995; Kale, 1998; Lalitha *et al*., 2000). Vermicast increases the inorganic salt concentration which is used by the plant root system. Soyabean and wheat production increase 51% and 47% respectively by the use of earthworms and their vermicast (Palanisamy, 1996). Vermicomposting positively modulates the functioning of organic nutrients in the soil, mucus present in the vermicast speed up the primary breakdown of organic residue into the simpler compound which easily absorb by plants (Lavelle, 1988; Six *et al*., 1998; Kumar *et al*. 2019). Organic matter ingestion by earthworm from the soil, mixing them with gut mucus and convert them into humus (Jairajpuri, 1993). The feeding mechanism of earthworm function as a soil fertility enhancer because earthworms improve soil aeration, nutrient content and increase microbial activity (Hickman and Reid, 2008; Lemitiri *et al*., 2014; Medina *et al*., 2019). Earthworms burrowing and nutrient-rich mucus-secreting habit increase the soil profile by enhancing the physical, chemical, and microbial activity (Lin *et al*., 2016; Le Bayon *et al*., 2021). Organic matter in the gut contains a high level of nutrients and water as compared to nutrients and water present in the soil and these organic matters after digestion excrete out from the anus in the form of vermicast which is enriched with a high nutrient content that improves the soil ecosystem (Buck *et al*., 2000; Singh *et al*., 2016). In vermicast high nutrient content of N, P, K, and Ca is available which is easily absorbed by the plant root system and enhance the crop productivity (Bhadauria and Ramakrishnan, 1989).

Technologies of vermicompost production

Vermitechnology is a scientific method in which we use epigeic (surface feeder) and endogeic (subsurface feeder) species of earthworm for the conversion of biowaste into the vermicast with the help of soil microorganisms. Vermicomposting is the process of the decomposing of the biodegradable organic waste with the use of worms and microorganisms into the vermicast which is nutrient-rich organic manure. By the use of earthworms, we decompose organic biodegradable waste into the manure (Gunadi *et al*., 1997) and minimize the waste impact on mankind. In 21st century rapid civilization, industrialization, and urbanization generate enormous waste from various sectors. In vermicomposting kitchen waste, institutional waste, paper waste, industrial waste, agricultural waste, and cow dung are used for earthworm feeding and earthworm convert these organic waste into manure. The role of earthworm in the formation of vermicompost from the biodegradable organic waste and improve fecundity of soil since 1881 by Darwin. The process of decomposition of waste into nutrient-rich manure was established by Kale *et al*. (1982) and Ismail (1993). Epigeic species of earthworms are extensively used in the vermicomposting like *Eisenia fetida, Eudrilus eugeniae, Eisenia andrei, Perionyx excavatus,* and *Lumbricus rubellus* are the most commonly used species in vermicomposting. Endogeic and anecic species of earthworms are not good for vermicomposting because both the species are not surface decaying material feeders, they live inside the soil by making horizontal and vertical burrow respectively but both the species are very useful in nutrient recycling and nutrient mixing in the soil. For this reason, endogeic and anecic species of earthworms are used for the modification of soil texture. Application of vermicompost on the agricultural practices we can minimize the negative impact of chemical fertilizers on the crops (Figure 3) . So by the use of vermicomposting we can easily decompose organic waste into nutrient rich organic manure. This technique convert the biodegradable waste into the humus like product without harming the environment (Tables 1 and 2). Compost obtain from the vermicomposting process is odorless, nutrient-

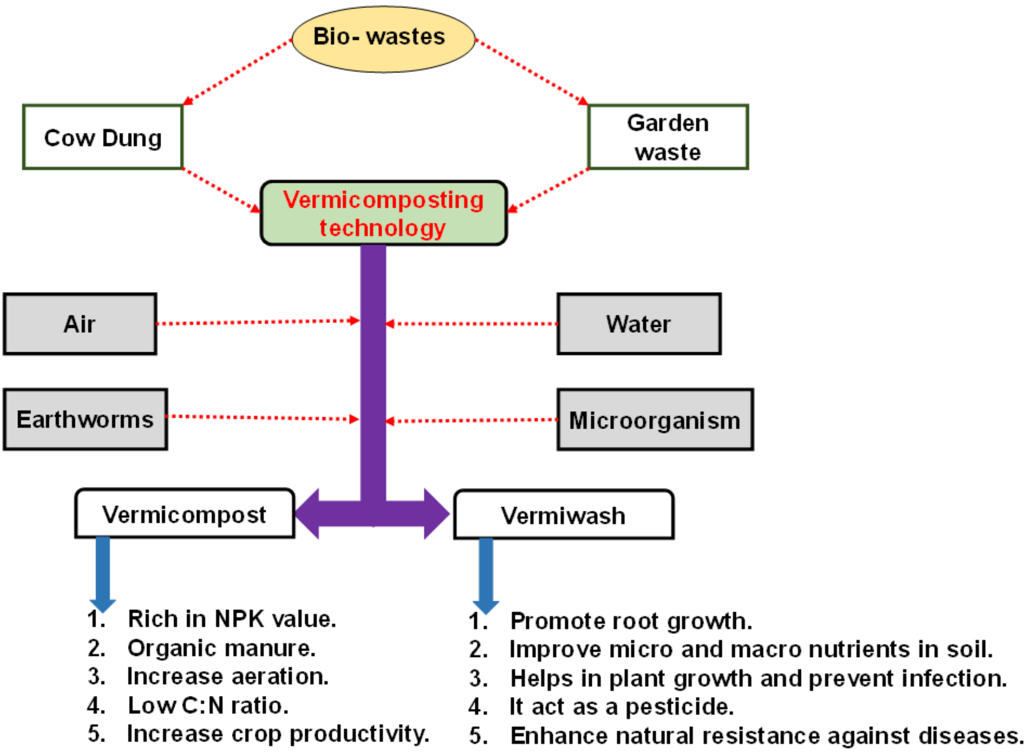

Figure 3. Vermicomposting process and use of vermicompost and vermiwash.

rich, and has many insecticidal properties (Rajiv *et al*., 2010; Sinha *et al*., 2011; 2013).

Future scope and recommendation

The future of vermitechnology in the field of agriculture is very bright as excessive use of pesticides and chemical soil productivity enhancer affect human health and soil health very badly. To overcome this problem whole world move toward organic farming. Vermicomposting is a very cheap and easier method to minimize this problem. By the use of earthworm minimize pesticide use in the crop field. To better understanding, the earthworm's role in agro ecosystems stabilization, improving soil texture, improve the microbial community in soil which helps in nitrogen fixation, and determine the factor that influences or inhibit the earthworm activity need more research. Earthworms are found all over the world except desert and snowy climate. Which species best suitable for organic waste decomposition and environment friendly and best adapted for their geographical climate. To understanding this problem needs more research in the field of earthworm biology.

Table 1. Approximate physiochemical properties of vermicast (Perera and Nanthakumaran; 2015).

Properties	Vermicompost	Compost	Soil
Organic matter	17.77%	76.90%	20.72%
Nitrogen	0.91%	1.15%	0.48%
Phosphorous	0.14%	0.17%	0.11%
Potassium	0.2%	0.6%	0.5%
Carbon	9.90%	44.35%	11.95%
C/N ratio	10.87%	38.56	24.85
pH	6.98	7.21	7.25
Electrical conductivity	1.1	0.2	0.4
Moisture contents	15.58%	12.20%	11.64%
Bulk density	0.5 g cm^{-3}	1.3 g cm^{-3}	1.6 g cm^{-3}
Particle density	2.49 g cm^{-3}	2.50 g cm^{-3}	2.68 g cm^{-3}
porosity	0.76	0.48	0.40

Table 2. Studies on utilization of industrial wastes and organic amendments for vermicomposting.

Industrial waste	Organic amendments	Earthworm species	References
Paper mill waste	Primary sewage sludge	*Eisenia andrei*	Elvira *et al*. (1996)
Paper mill waste	Cattle manure	*Eisenia andrei*	Elvira *et al*. (1998)
Paper mill sludge	Cow dung	*Eisenia fetida*	Kaur *et al*. (2010)
Food industry sludge	Cow dung and Poultry droppings.	*Eisenia fetida*	Banu *et al*. (2005)
Solid textile mill sludge	Cow dung	*Eisenia fetida*	Kaushik and Garg (2003)
Textile industry waste	Cow dung and soil	*Eisenia fetida*	Garg *et al*. (2006a, b)
Sugar mill filter cake	Horse dung	*Eisenia fetida*	Sangwan *et al*. (2008)
Olive oil industry waste	Municipal biosolids	*Eisenia andrei*	Benitez *et al*. (2005)
Coffee pulp Pressmud	Cow dung	*Perionyx ceqlanensis*	Prakash and Karmegam (2010)
Sugar industry sludge	Cow dung, biogas slurry and wheat straw	*Eisenia fetida*	Suthar (2010)
Sago industry solid waste	Cow dung and poultry manure	*Eisenia fetida*	Subramanian *et al*. (2010)
Distillery sludge	Cow dung	*Eisenia fetida*	Suthar (2008)
Dairy industries sludge	Sewage sludge	*Eisenia fetida*	Gratelly *et al*. (1996)
Solid paper mill waste	Brewery yeast	*Lumbricus terrestris*	Butt (1993)

Conclusion

Several studies conclude that the role of earthworm diversity to improve soil fertility and enhance crop productivity. Earthworms digest organic matter and convert them into the humus. Humus has a high value of inorganic salts like N, P, K, and Ca these are the main integrant that enhances the crop productivity. The earthworm found in the different layer of the soil like epigeic earthworm found in the upper layer of the soil and not built the permanent burrow so this species is not involved in the mixing nutrients and aeration in the soil but the composting process is very fast as it decomposes biodegradable organic matter into the nutrient-rich manure. Vermicast or earthworm manure changes the soil profile, texture, and stabilization of the microbial community in the soil. Endogeic earthworms live in the horizontal burrow and feed on soil and some plant litter and help in the mixing of nutrients in the soil and change the texture of the soil. Anecic earthworms live in the deeper parts of the soil by making a vertical burrow. The decomposition efficiency of organic waste of anecic earthworms is very low but this species eat organic wastes like plants litters, leaves, decaying organic wastes on the soil surface. For feeding they come out their burrows at night and feed then returns to their burrows. They excrete their droppings in their burrows and changes texture, aeration, nutrient content in the soil. So the impact of the earthworm biodiversity on soil fertility and crop improvement is very important.

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Chapter
[16]

Role of microbial diversity in ecosystem sustainability

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Abstract

Microorganisms are ubiquitous i.e. they are present nearly everywhere in world. They are huge in number and play significant role in environment. Microorganisms have several vital roles in ecosystems: decomposition, oxygen production, evolution, and symbiotic relationships with plants etc. Microbial enzymatic activity is responsible in cyclic of essential nutrients. Microbial diversity can be characterized on the basis of morphology, physiology, genetic and geography etc. The microbial ecology is relationship between microorganisms and their biotic and abiotic environment. Microbes are huge in number and significant role in environment. Microorganisms have several vital roles in ecosystems such as decomposition of complex molecules, produce oxygen, symbiotic relationships with plants, recycling of nutrients and bioremediation. Plant growth promoting microorganisms enhances plant growth by production of plant growth hormones, enzyme production, siderophore production and HCN production etc. Microorganism uses processes such as Biodegradation, Biotransformation, and Co-metabolism for degradation of xenobiotic compounds. Few specific microorganisms are use in mining industry which process is known as bioleaching.

Keywords Bioleaching, Microbial diversity, Microbial ecology, PGPR, Xenobiotics

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Introduction

Microorganisms are microscopic living from which may exist in unicellular form and multicellular forms. Diversity means variation so in simple word; microbial diversity is variation in microorganisms. This microbial diversity can be characterized on the basis of morphologically, physiologically, genetically and geographical etc. Anything which has variation, it comes under diversity. The diverse groups of communities of microorganisms are classified in to Bacteria, Archaea and Eukaryote. In morphological diversity, microbes are classified on the basis of various forms such as unicellular, multi-cellular, rod shape, spherical, spiral, oval, flagellate, branched, unbranched etc.

Morphological diversity: These microscopic organisms have unique morphology and we can observe them with help of staining under microscope. In general, shape of Bacteria like a ball is called cocci, rod shaped bacteria are known as bacilli and some rod shaped bacteria are curved, spiral shaped bacteria is called as spirilla (singular spirillus) (van Teeseling *et al.*, 2017). Some bacteria are flagella which is responsible for motion and classified into to Monotrichous- Single flagella at one end, Amphitrichous- single flagella at both ends, Lophotrichous- Tuft of flagella at one or both ends, Peritrichous- flagella surrounding the bacterial cell (Holt *et al.*, 1994). Further, Unicellular fungi forms oval type structure which broadly term as Yeast and other eukaryotic multi cellular forms are known as fungi which may bear spore beading structure like sporangia containing motile spore - zoospores or non-motile spore aplanospore which are asexual spores and other types of sexual spores such as Ascospore, zygospore etc. (Stajich *et al.*, 2009; Willey *et al.*, 2017).

Physiological diversity: Microbial physiology is defined as the study of how microbial cell structures, growth and metabolism function in living organisms. It is also conveyed as the study of microbial cell functions which includes the study of microbial growth and microbial metabolism. Microorganism is using various metabolic pathways for growth, repair and multiplication. There are two group of microorganisms based on oxygen metabolism- aerobic and anaerobic microbes (Willey *et al.*, 2017; Moat *et al.*, 2002). Aerobic microorganisms are use oxygen for metabolic activity and process is known as oxidation. Another group of anaerobic cannot perform activity under aerobic condition therefore they are called as anaerobic microbes and this process is known as fermentation. Other factors such as nutrients, pH, temperature etc. are also affected metabolic activity. In other words, we can say enzymes are responsible for metabolic activity, which are affected by environmental parameters. Various metabolic biochemical processes are come under this diversity (Willey *et al.*, 2017). Among micro-organisms fungi produce maximum exogenous enzymes in environment. An Autotrophic microbe can produce its own food using light, water, carbon dioxide, or other chemicals but other group which cannot manufacture its own food by carbon fixation and therefore derives its intake of nutrition from other sources of organic carbon, mainly plant or animal matter are known as "Heterotroph" (Willey *et al.*, 2017; Moat *et al.*, 2002).

Genetic diversity: Genetically diversity means variation in DNA sequence. A genome is an organism's complete set of DNA, including all of its genes. Each genome contains all of the information needed to build and maintain that organism. Microbial genomes are widely variable and reflect the enormous diversity of bacteria, archaea and lower eukaryotes. The molecular-phylogenetic studies, researchers have compiled an increasingly robust map of evolutionary diversification showing that the main diversity of life is microbial, distributed among three primary relatedness groups or domains: Archaea, Bacteria, and Eucarya (Pace, 1997). One major difference between the genomes of microorganisms and higher eukaryotes, is the presence of circular, extra-chromosomal DNA called plasmids. Plasmids can be transferred via horizontal DNA transfer from on cell of the same generation to another, mediating the rapid evolution of many different organisms (Bohlin *et al.*, 2017; Bohlin and Pettersson, 2019). It means, each microorganism have its own specific genome. This genomic information can be used for identification and qualitative analysis of microorganism.

Geographical diversity: Microorganisms are distributed in all over the world which includes plants, animals, and environment. Microbes show diversity in pH which is an important determinant of microbial community composition and diversity. Most Microbes grow best around neutral pH values (6.5 - 7.0), but some thrive in very acid conditions and some can even tolerate a pH as low as 1.0. Such acid loving microbes are called acidophiles. Even though they can live in very acid environments, their internal pH is much closer to neutral values. But Alkaliphiles are a class of extremophilic microbes capable of survival in alkaline (pH roughly 8.5–11) environments, growing optimally around a pH of 10 (Gomes and Steiner, 2004; Gupta *et al.*, 2013). Microorganism shows diversity on the basis of temperature and they are classified into 5 types.

Psychrophiles grow well at from 0°C to 20°C and have an optimum growth temperature near to 15°C. They are readily isolated from Arctic and Antarctic. Another types of microbes are *psychrotrophs* or *facultative psychrophiles* which can grow at 0 to 7°C even though they have maximum growth ranges between 20 and 30°C. Other group, *Mesophiles* are microorganisms with growth optimum around 20 to 45°C. Further, *thermophiles* where microorganisms can grow at temperatures of 55°C or higher. These organisms flourish in many habitats including composts, self-heating hay stacks, hot water lines, and hot springs. In fifth group, a few thermophiles can grow at 90°C or above and some have maxima above 100°C and they are known as *hyperthermophiles* (Gupta *et al.*, 2014). Few Archea such as *Pyrobaculum*, *Pyrodictium*, *Pyrococcus* and *Melanopyrus* and fungi such as *Ascomycete* and *Zygomycete* family can multiply at high temperature (Busk and Lange, 2013; Gupta *et al.*, 2014). *Thermotoga maritime* and *Aquifex pyrophilus* is belong to bacterial group can exhibit the highest growth temperatures of 90 and 95°C respectively (Haki and Rakshit, 2003; Kumar *et al.*, 2011; Gupta *et al*., 2014).

Microbial ecology and microbial niche

Microbial ecology is the science that specifically examines the relationship between microorganisms and their biotic and abiotic environment i.e. microbial ecology applies the general ecological principles to explain life functions of microorganisms *in situ*, i.e., directly in their natural environment rather than simulated under artificial laboratory conditions *ex situ* or *in vitro* (Panikov, 2010). The niche theory is based on the assumption that the species composition of an ecosystems entirely determined by environmental conditions, a process known as habitat filtering (Dumbrell *et al.*, 2010). Simply, we can say the ecological niche of a microorganism describes how it responds to the distribution of resources and competing species, as well as the ways in which it alters those same factors in turn. In essence, the niche is a complex description of the ways in which a microbial species uses its environment. The accurate ecological niche of a microbe is primarily determined by the specific metabolic properties of Microorganism (Horner-Devine *et al*., 2007; Faust and Raes, 2012). Understanding of microbial ecology is difficult as microbial ecology is not permanent in site. The microbial ecology changes as change number and type of microorganisms under non-living habitats. Microbial ecologists have examined whether microbial communities are distinct in different environments, whether microbial diversity changes with habitat heterogeneity and distance, and whether microbial diversity shows explainable patterns of distribution comparable to such of microorganisms (Rosenzweig, 1995), the productivity-diversity relationship (Rosenzweig, 1995) or patterns of co-occurrence (Horner-Devine *et al*., 2007). The microbial ecologists study the contributions of microorganisms to the carbon, nitrogen, and sulfur cycles in soil and in freshwater. The study of pollution effects on microorganisms also is important because of the impact these organisms have on the environment. Microbial ecologists are employing microorganisms in bioremediation to reduce pollution effects (Willey *et al*., 2017).

Role of microorganisms in an ecosystem

Microorganisms are ubiquitous i.e. they are present nearly everywhere in world. They are huge in number and play significant role in environment. Microorganisms have several vital roles in ecosystems: decomposition, oxygen production, evolution, and symbiotic relationships with plants etc. Microbial enzymatic activity is responsible in cyclic of essential nutrients. In soil, microbial community is linked with ratio of nutrient i.e. carbon: nitrogen: phosphorous: sulphur ratio. At the same time, these ratios might be modulated by the different nature of available organic matter in each substratum and by the water nutrient concentrations.

Decomposition: Decomposers are present in dead animal or plant matter and they break down into more basic molecules. These micro-organisms produce diverse exogenous enzymes which convert complex form to simplest form which process is known as decomposition. In this decomposition process, various different products are released in environment such as carbon dioxide (CO_2), energy, water, plant nutrients and resynthesized organic carbon compounds. The successive decomposition of dead material or modified organic matter results in the formation of a more complex organic matter called humus (Juma, 1998; Bani *et al*., 2018). So the process of decomposition provides nutrients that future plants and animals will be able to reuse, making soil more fertile.

Nutrients recycling: Microorganisms play important role in circulation of nutrients in ecosystem. Microorganism produces enzymes to degrade complex material into simplest form which can be utilized by other living forms. Further, microorganisms are responsible for running biogeochemical cycle.

Nitrogen fixation: Microorganisms have capability to fix atmospheric nitrogen. On the basis of such nitrogen fixing tendency nitrogen fixing microorganisms and classified into two group symbiotic nitrogen fixer and free living (non-symbiotic) nitrogen fixer (Deshwal *et al*. 2013a). The symbiotic interactions between a legume and rhizobia result in a unique, nitrogen fixating plant organ, the nodule symbiotic nitrogen fixation throughout nodulation in legumes is well known, which help to reduce the application of inorganic N and can also play a major role as green manure in improving the soil fertility (Deshwal *et al.*, 2013b; Deshwal and Singh, 2014; Ney *et al.*, 2019). According to Postgate (1982), the atmosphere contains about 10^{15} tones of N_2 gas and nitrogen cycle involves the transformation of some 3×10^9 tonnes on global basis but lighting can fix atmospheric nitrogen i.e. transformation and 10% of world supply of nitrogen meets out by this process (Sprent and Sprent, 1990). The fertilizer industry also provides chemically fixed nitrogen globally. The consumption of fertilizer N increased from 8 to 17 Kg. ha^{-1} of agriculture land in the 15-year period from 1973 to 1988 (FAO, 1990; Deshwal *et al.*, 2013; Mahmud *et al.*, 2020).

More than 100 years biological nitrogen fixation (BNF) has commanded the attention of scientists concerned with plant mineral nutrition and it has been exploited extensively in agricultural field (Dixon and Wheeler, 1986; Burris, 1994). Frages (1992) suggested that ecological principles and practices that are appropriate for the manipulation of rhizobia prove suitable model for other soil microorganism as well. Brockwell and Bottomley (1995) concluded that in particular efficient substitute for fertilization of crops and pastures occurs with the organic N. Recently, Ramírez-Puebla *et al.* (2019) mentioned that nearly 50% of the total nitrogen in crop fields is the contribution of BNF by diazotrophic bacteria of the total biosphere nitrogen.

Bacteria of family Rhizobiaceae are symbiotic and effectively convert atmospheric nitrogen which is utilized by the host. Rhizobiaceae family contains six genera namely *Rhizobium*, *Sinorhizobium*, *Mesorhizobium*, *Allorhizobium*, *Azorhizobium* and *Bradyrhizobium* (Deshwal and Chaubey, 2014). The Free -living diazotrophs correspond to a small fraction of the plant rhizospheres ecosystem, and they belong to alphaproteobacteria (Rhizobia, Bradyrhizobia, Rhodobacteria), betaproteobacteria (Burkholderia, Nitrosospira), gammaproteobacteria (*Pseudomonas*, *Xanthomonus*), firmicutes, and cyanobacteria (Morris and Schniter, 2018; Deshwal and Thapliyal, 2019), Actinomycetes and Frankia sp. (Deshwal and Tarik,2018), Cyanobacteria (mainly Nostoc sp.), *Azospirillum* spp., *Azoarcus* spp. and Herbaspirillum (Burén and Rubio, 2017), *Clostridium pasteurianum*, *Klebsiella oxytoca* (Yates and Jones, 1974), *Azotobacter vinelandii* (Poole, 1997).

Carbon rotation in environment: Carbon is an essential element for life as we know it because of its ability to form multiple, stable bonds with other molecules. Without carbon, none of these molecules could exist and function in the ways that permit the chemistry of life to occur. Various carbon cycle steps are given below

Carbon in the Atmosphere: Carbon dioxide gas (CO_2) can released into the atmosphere through the activities of living things, such as the exhalations of animals, the actions of decomposer organisms, and the burning of wood and fossil fuels by humans. The CO_2 gas in atmosphere is the starting point of the carbon cycle (Lu and Conrad, 2005; Trumbore, 2006; Le Quere *et al.*, 2009).

Producers: Producers such as plants absorb carbon dioxide from the atmosphere under sunlight and use CO_2 to build sugars, lipids, proteins, and other essential building blocks of life.

Other producer organisms such as cyanobacteria are crucial to life on Earth because they can turn atmospheric carbon into living matter (Lu and Conrad, 2005; Trumbore, 2006).

Consumers: Herbivorous animals consume these plant form growth and metabolic activity. They use some of these carbon compounds from food to build their own bodies but much of the food they eat is broken down to release energy. Carnivorous consume primary consumers and uptake nutrients (Liang and Balser, 2011)

Decomposers: Plants and animals that die without being eaten by other animals are broken down by other organisms, called "decomposers." Decomposers include many bacteria and some fungi. Decomposers break down the chemical bonds in their food molecules. They create many chemical products, including in some cases CO_2 (Liang and Balser, 2011).

Human Activities: Recently, humans have made some big changes to the Earth's carbon cycle. By burning huge amounts of fossil fuels and cutting down roughly half of the Earth's forests, humans have decreased the Earth's ability to take carbon out of the atmosphere, while releasing large amounts of carbon into the atmosphere that had been stored in solid form as plant matter and fossil fuels (Le Quere *et al.*, 2009).

Release of phosphorus: Phosphorus is one of the important element for all forms of life. The phosphate (PO_4) makes up an important part of the structural framework that holds DNA and RNA together. Phosphates are also a critical component of ATP (adenosine triphosphate phosphate) which is a cellular energy carrier (Willey *et al.*, 2017). Few microbial strains has capability to solubilize non-solubilizing phosphorous in soil and as a results increase plant growth and productivity (Deshwal and Kumar, 2013a). In field study, Chabot *et al.* (1996) observed that phosphate solubilization by strains of *R. leguminosarum* bv. *phaseoli*, was the most important mechanism of maize and lettuce growth promotion. Antoun *et al.* (1998) also found that *Bradyrhizobium* sp (Lupinus) solubilized phosphate. Similarly, Dashi *et al.* (1998) observed that plant growth promoting rhizobacteria solubilized phosphate and accelerate nodulation, increase nitrogen fixation activity by field grown *Glycine max* L. Merr. under short season conditions.

Release sulphur into environment: Sulphur is an essential part of all living cells and Sulphur containing amino acids are always present in almost all kinds of proteins. The Plants can absorb directly the sulphur containing amino acids, e.g., cystine, homocysteine, cysteine and methionine. Besides S-containing amino acids, it is also an important part of growth factors like thiamine, biotin and lipoic acids (Willey *et al.*, 2017). However these amino acids fulfil only a small proportion or requirements for sulphur to the plants. To fulfil rest of the requirements of plants, sulphur passes through a cycle of transformation mediated by microorganisms. Sulphur compounds involved in the sulphur cycle are H_2S, S°, thiosulphate, sulphite (SO_3^{--}) and sulphate (SO_4^{--}). Most common forms of sulphur are H_2S, S° and SO_4^{--}. The greatest reservoir of sulphur in the biosphere is the sulphate in the oceans (Tourna *et al.*, 2014; Zhao *et al.*, 2017).

- **Source:** The major source of sulphur in marine environment is sulphate. While in the lithosphere, the sulphur is found as sulphate and iron sulphide (FeS). The metal sulphides (FeS) are readily oxidized to sulphates by both biological and chemical processes (Willey *et al.*, 2017).

- **Assimilatory sulphate reduction:** In most habitats, sulphates are available to plants and microorganisms which is assimilated into sulphydryl compounds (R-SH) that becomes a part of biomass of living organism. This reduction process in which sulphate becomes biomass is known as Assimilatory Sulphate reduction. Various microorganisms and green photosynthetic plants are involved in the process. Since animals can only uptake the reduced form of sulphur it is an important step to transfer the S into a food chain (Kumar *et al.*, 2018).
- **Release of H_2S:** H_2S is release to biosphere by both aerobic and anaerobic processes. They can be either release from decomposition of organic compounds (Desulphurylation) or by reduction of inorganic sulphate (Dissimilatory sulphate reduction) (Willey *et al.*, 2017; Kumar *et al.*, 2018).
- **Oxidation of hydrogen sulphide (H_2S) to elemental sulphur:** Hydrogen sulphide undergoes decomposition to produce elemental sulphur by the action of certain photosynthetic sulphur bacteria. (Kumar *et al.*, 2018; Fuentes-Lara *et al.*, 2019).
- **Oxidation of elemental sulphur to sulphates:** Elemental form of sulphur accumulated in soil by earlier described processes cannot be utilized as such by the plants. It is oxidized to sulphates by the action of chemolithotrophic bacteria of the family Thiobacteriaceae (*Thiobacillus thiooxidans*, *Thiobacillus ferroxidans, Thiobacillus denitroficans*) (Willey *et al.*, 2017).

Micronutrient and macronutrient iron: Like other micronutrient and macronutrient iron is also necessary for living organism. Iron is the fourth most abundant element in the earth. Iron oxides, comprising minerals such as hematite, magnetite and limonite are most abundant of metal oxides in soil (Schwertmann and Taylor, 1989). Iron is required for large variety of metabolic process in virtually all organisms (Crichton *et al.*, 1987) except *Lactobacilli* (Archibald, 1983). In aerobic condition, iron is present in soil of neutral pH as insoluble ferric hydroxide polymers are not available biologically (Linhsay, 1979). Most microorganisms have efficient high affinity iron uptake system, to fulfil their requirements. In this process siderophore; low molecular weight iron (III) chelating agents are synthesized (Neilands, 1981). Siderophores chelate insoluble iron and solubilize iron and ferric siderophore complex are taken up by the cell through specific membrane receptors (Neilands, 1982).

Plant growth promotion: Plant Growth Promoting Microorganism are beneficial microbes which provides plant growth and increase soil fertility. These microorganisms release plant growth hormones, antimicrobial agent like HCN which indirectly kill pathogenic microbes, siderophore etc. Such microorganisms increase plant growth activity and productivity.

- **Plant growth hormones:** Plant growth-promoting rhizobacteria (PGPR) includes a wide variety of bacterial strains from different taxonomic groups that inhabit plant roots and their rhizosphere. Different PGPR strains can synthesize phytohormones such as auxin, ethylene, cytokinin, gibberellin, abscisic acid, jasmonic acid and salicylic acid (Tsukanova *et al.*, 2017). Plant growth promoting rhizobacteria produce plant growth hormones such as IAA which enhance the plant growth (Deshwal *et al.*, 2013a; Deshwal and Kumar, 2013b). IAA is well-known plant growth promoting hormones and 96% symbiotic nitrogen fixing rhizobia produced IAA (Arora *et al.*, 2001; Deshwal *et al.*, 2013). Lippman *et al.* (1995) observed that PGPR could directly enhance plant growth by IAA production and increasing nutrient uptake. Noel *et al.* (1996) observed under gnotobiotics conditions, a direct growth promotion of the early seedling root, appears to involve the growth regulators such as IAA and cytokinin. Gibberellins are a group of hormones that perform various functions in the plant organism. They are the key regulators of reproductive organ formation and development and ripening of fruit and viable seeds (Plackett and Wilson, 2016). PGPR can influence the amount of endogenous gibberellin in plants, in a fashion similar to other hormones. For example, some PGPR strains can synthesize gibberellins (Bottini *et al*., 2004; Deshwal *et al*., 2013).

- **HCN production:** Few specific microorganisms produce one hydrogen cyanide (HCN) which has antimicrobial activity. This is one of the reasons, that plant growth promoting microorganisms. The HCN producing microorganisms control growth of different type of pathogens (Bagnasco *et al*., 1998; Deshwal *et al*., 2013). Previously, Nautiyal (1997) screened *Rhizobium* strains, among isolated 256 bacterial strains *Rhizobium* NBRI 19513 completely inhibited growth of *Fusarium oxysporum*, *Rhizoctonia bataticola* and *Pythium* sp. *in vitro*. Deshwal *et al.* (2003) observed that HCN producing *Bradyrhizobium* strains inhibited the growth of *M. phaseolina*.
- **Siderophore :** Siderophore effectively control the disease chlorosis: The mechanism by which plant avoid iron (chlorosis) are both more diverse and less investigated than the siderophore mediated iron up take system of microorganisms. Three strategies of iron assimilation have been identified in plant (Bienfait, 1989). Strategy I, found in non-gramineous monocots and all dicots, involves acidification of the rhizosphere, thus increasing iron solubility by approximately 10^3 per pH unit, the reduction of Fe^{3+}ion and Fe (III) chelates to Fe^{2+} ion and uptake of Fe (II) occurs. Strategy II, observed that in graminaceous monocots secretion of iron chelating agent (phytosiderophore) of mugineic acid family involves (Sugiura *et al.*, 1981) and where as in strategy III, was the uptake of microbial Fe (III) siderophores take place. Although extensive research has been directed to correct chlorosis by the applications of available iron compounds to the soil. Hence the, the siderophores production by rhizobial strains would prove considered as a potential way to improve nodulation and N_2 fixation in iron deficient conditions (Carson *et al*., 1992; Deshwal *et al*., 2013).

Degradation of xenobiotic compounds

Xenobiotics are released into the environment by human activities, and they often cause problems such as environmental pollution, since most such compounds cannot be readily degraded, and have harmful effects on human beings and the natural ecosystem. However, some microorganisms that degrade man-made xenobiotics have been isolated. Most of these aerobic xenobiotics-degrading bacterial strains use xenobiotics as their sole source of carbon and energy, and thus they are excellent models for studying the adaptation and evolution of bacteria in the environment. Although plants have the inherent ability to detoxify some xenobiotic pollutants, they generally lack the catabolic pathway for complete degradation/mineralization of these compounds compared to microorganisms (Eapen *et al.*, 2007). Three major processes such as *Biodegradation*, *Biotransformation*, and *Co-metabolism* are responsible for degradation of xenobiotic compounds. Microorganisms are perform most of the biodegradation of both natural products and industrial chemicals. Collectively, microorganisms play a key role in the biogeochemical cycles of the Earth. The substances transformed (conversion into another form) or degraded by microorganisms are used as a source of energy, carbon, nitrogen, or other nutrient, or as final electron acceptor of a respiratory process (Fetzner, 2000).

The "*biodegradation*" involves the breakdown of organic compounds, usually by microorganisms, into biomass and less complex compounds, and ultimately to water, carbon dioxide, and the oxides or mineral salts of other elements present. Further, "*Biotransformation*" is the metabolic modification of the molecular structure of a compound, resulting in the loss or alteration of some characteristic properties of the original compound. "*Biotransformation*" may effect the solubility, mobility in the environment, or toxicity of the organic compound. A microbial population growing on one compound may fortuitously transform a contaminating chemical that cannot be used as carbon and energy source, a process referred to as 'co-metabolism'. The phenomenon has also been called 'co-oxidation' and 'gratuitous' or 'fortuitous' metabolism. Usually, the primary substrate induces production of (an) enzyme (s) that fortuitously alter (s) the molecular structure of another compound (Fetzner, 2000; Willey *et al.*, 2017). Aerobic degradative bacteria of xenobiotics are *Pseudomonas*, *Gordonia*, *Bacillus*, *Moraxella*, *Micrococcus*, *Escherichia*, *Sphingobium*, *Pandoraea*, *Rhodococcus*, and anaerobic xenobiotics degradative bacteria are *Pelatomaculum*, *Desulphovibrio*, *Methanospirillum*, *Methanosaeta Desulfotomaculum*, *Syntrophobacter*, *Syntrophus* (Varsha *et al.*, 2011).

Microbial leaching

In general, bioleaching is a process described as "the dissolution of metals from their mineral sources by certain naturally occur microorganisms" or the use of microorganisms to transform elements so that the elements can be extracted from a material when water is filtered through it (Brierley, 1978; Lundgren and Malouf, 1983). Microbial extraction of metals has been in application for ore leaching for centuries, though the mechanism remained unknown. Specifically copper was recovered by man as early as 1000 BC from metal laden waters which passed through copper ore deposits. Specific Bacteria capable of oxidising Sulphur compounds to sulphuric acid (Devasia *et al.*, 1993). This was followed by the isolation of the iron and sulphur oxidising bacteria, *Thiobacillus ferrooxidans* (now called *Acidithiobacillus ferrooxidans*) to lay the foundation for subsequent research into the role of microorganisms in leaching. A consortium of microorganisms namely *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, *Leptospirillum ferrooxidans*, *Sulpholobus* spp. and *thermophilic* bacteria including *Sulpholobus thermosulphidoxidans* and *Sulpholobus brierleyi* are known to be involved in bioleaching. Anaerobes would also be found in leaching areas (Devasia *et al.*, 1993; Botero *et al.*, 2007; Pollmann *et al.*, 2016).

Bioleaching of copper: Biological copper leaching is practiced in many countries including Australia, Canada, Chile, Mexico, Peru, Russia and the United States of America. Copper recovery from bioleaching accounts for about 25% of the world copper production. Following the initial isolation of *Acidithiobacillus ferrooxidans* from coalmine water in 1947, studies quickly disclosed its presence in copper-leaching operations. *Acidithiobacillus ferrooxidans* is also found in the Malanjkhand Copper Mines (Devasia *et al*., 1993; Cornejo *et al*., 2008).

Bioleaching of uranium: Uranium leaching proceeds by the indirect mechanism as *Acidithiobacillus ferrooxidans* does not directly interact with uranium minerals. The role of *Acidithiobacillus ferrooxidans* in uranium leaching is the best example of the indirect mechanism (Devasia *et al*., 1993; Tsuruta, 2007).

Bioliberation of gold: Iron- and sulphur-oxidising acidophilic bacteria are able to oxidise certain sulphidic ores containing encapsulated particles of elemental gold, resulting in improved accessibility of gold to complexation by leaching agents such as cyanide. Bio-oxidation of gold ores is a less costly less polluting alternative to other oxidative pre-treatments such as roasting and pressure oxidation (Devasia *et al*., 1993; Natarajan, 1998).

Conclusion

Microbial diversity is variation in microbes on the basis of physical, biological, genetically or geographical. This diversity play an important role in various diverse ecology where variation in pH, temperature, aerobic or anaerobic, nutrients, xenobiotic compounds and toxic environment. Microbes survive unfavourable condition and convert complex, toxic material into simple and non-toxic material. Further, diverse plant growth promoting microbes increase soil fertility, plant growth and productivity of essential crops. Such diverse microorganisms are use in agriculture, food and dairy, pharmaceutical, hospital, cosmetic, mining, environment cleaning, waste management etc. Without microbial diversity, the world cannot survive.

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Chapter
[17]

Ecology and diversity of plant aphids in Garhwal region of Uttarakhand, India

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Abstract

Arthropod insect aphids, also known as plant lice, are small soft bodied insects that suck the sap of the plant. Which belong to the subfamily Aphidinae. There are about 400 species of aphids under 60 genera worldwide. Out of which 125 species of aphids are found under 25 genera in India and in Uttarakhand (plain region to very high altitude) under 4 genera of aphids 65 species of aphids are found, of which the genus Aphidius represents the largest number of species. Aphids are abundant in temperate climates and attack a wide variety of plants causing great damage to agricultural crops, horticultural fruits and vegetables. Its outbreak is influenced by temperature, humidity and other environmental factors. Aphids are small, soft bodied, wingless, viviparous and parasitoid insects which have a pair of tube like projections cornicles or wax secreting tube on the abdomen, that may stunt plant growth, produce plant galls, transmit plant virus diseases, and cause the deformation of leaves, buds, and flowers. They affect the crops like mustard, cabbage, pea, potato, bean, lemon, cotton etc. and flowers like rose, lily, marigold etc. There is a lack of information about aphid diversity, ecology and inventory in the mountainous region. Thus in this study an attempt has been made to review and survey the diversity of aphids in the Uttarakhand Garhwal region.

Keywords Altitude, Aphidiinae, Genera, Temperate climate

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Introduction

Arthropod pests like aphids (Hemiptera) belong to family Aphididae also known as plant lice, greenfly, or ant cow group of sap-sucking, soft-bodied insects can damage plants and their leaves which are important for photosynthesis. Aphids are small, soft bodied, wingless, viviparous and parasitoid insects which have a pair of tube like projections cornicles or wax secreting tube on the abdomen, that may stunt plant growth, produce plant galls, transmit plant virus diseases, and cause the deformation of leaves, buds, and flowers. They affect the crops like mustard, cabbage, pea, potato, bean, lemon, cotton etc. and flowers like rose, lily, marigold etc. Aphids belong to Phylum - Arthropoda, Class - Insecta, Order - Hemiptera, Suborder - Sternorrhyncha, Superfamily - Aphidoidea, Family – Aphididae, sub family - Aphidiinae. Approximately 400 species placed under 60 genera of subfamily Aphidiinae have been described worldwide (Belshaw and Quicke, 2001). This subfamily was traditionally represented by four tribes, viz., Ephedrini, Praini, Aphidiini and Trioxini but molecular phylogenetic analysis have proved to be three viz., Ephedrini, Praini and Aphidiini (Smith *et al*., 1999) or five viz., Ephedrini, Praini, Monoctonini, Trioxini and Aphidiini tribes (Sanchis *et al.*, 2005).

In India, this subfamily is represented by 125 species belonging to 22 genera under four tribes viz., tribe Ephedrini with 4 genera viz. Toxares, Ephedrus, Indoephedrus and Neoephedrus; tribe Praini with 2 genera viz., Areopraon and Praon; tribe Aphidiini with 12 genera viz., *Adialytus, Aphidius, Archaphidus, Diaeretiella, Diaeretus, Indaphidius, Kashmiria, Lipolexis, Lysiphlebia, Lysiphlebus, Monoctonus* and *Pauesia* and tribe *Trioxini* with 4 genera viz., *Betuloxys, Binodoxys, Cristicaudus* and *Trioxys* occurring from the plains to very high altitudes of Himachal Pradesh, Jammu and Kashmir, West Bengal and Uttarakhand. An analysis of the literature reveals that as many as 95 species have been reported from North West India from the states of Delhi, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttar Pradesh and West Bengal; 41 species from the states of north east India viz., Assam, Manipur, Meghalaya, Nagaland, Sikkim and Tripura and 13 species from south India viz., Karnataka and Tamil Nadu. An inventory of the biodiversity of aphidiini parasitoids associated with aphids in India showed 123 species under 23 genera to be intensively and extensively exercising natural control. Aphids are cosmopolitan in distribution and are found abundant in temperate climate and attack a wide variety of plants (De Barro and Carver, 1997). The inventory has been reinforced with all associated details, mainly zoo-geographical distribution, parasitism potential attributes and other such relative details from primary sources so as to make it serve as an important start up tool for planning any IPM strategy, involving bio control of aphids (Dey and Akhter, 2007). Aphids are often controlled by natural enemies such as ladybird beetles, aphid lions, and lacewings. However, when economically or aesthetically damaging numbers are present, they can be controlled by insecticidal soaps, horticultural oils, and other traditional insecticides. Aphids cause great loss to agriculture crops, horticulture fruits and vegetables. Its outbreak is affected by temperature, humidity and other environmental factors (Bannerman and Roitberg, 2014). There is lack of information on the aphid diversity, ecology and inventory in mountain region. Thus an attempt has been made to review and survey the diversity of aphids in Uttarakhand Garhwal region.

Life cycle of aphids

The life cycle of the aphid is complicated. Wingless females, called stem mothers, reproduce without fertilization (parthenogenetically) throughout the summer. These stem mothers are unique in that they produce living young ones (viviparity) as opposed to eggs as occurs in most other insects. Eventually the plant containing the stem mother and her offspring becomes overcrowded. When this occurs, some offspring develop into adults with two pairs of large membranous wings. These winged adults fly to new plants. In late summer both males and females are produced. After they mate, the female lays eggs that survive the winter. In warm climates there may be no need for an overwintering egg stage, and continuous generations occur. The white woolly-ball appearance of many aphids is the result of wax-gland secretion. Aphids reproduce by thelytokous parthenogenesis in spring and summer under conditions of long day length and high temperatures. In aphids with a holocyclic life cycle, males and oviparous (sexual) females appear in late autumn and produce fertilized eggs for overwintering. Aphids employ the XO sex-determination system. Therefore, viviparous and oviparous females possess two X chromosomes, while males possess only one X chromosome. Males are produced parthenogenetically with the random loss of one X chromosome during the maturation division. Although oviparous females and males produce haploid oocytes and sperm, respectively, by reductive meiosis, only sperm possessing an X chromosome are viable (sperm lacking an X chromosome are degenerate). Therefore, the next generation, which will hatch as fundatrices in the spring, is entirely female (XX) i.e. Viviparous, parthenogenetic female; Oviparous, sexual female (Chan and Forbes, 2019) (Figure 1).

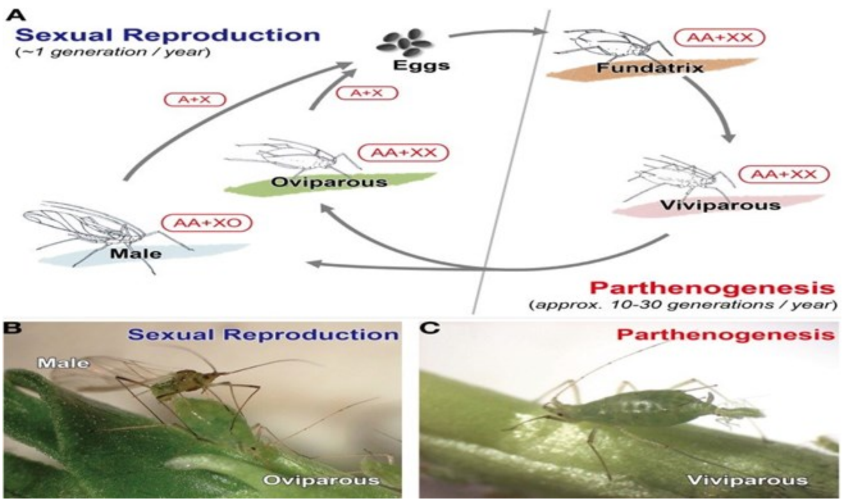

Figure 1. Typical annual life-cycle of aphids, (A) Schematic diagram of a typical holocyclic life cycle of aphids, (B) Sexual individuals (male and oviparous female) of *Acyrthosiphon pisum*, (C) viviparous female of *A. pisum*.

Aphids as vector for the viruses

Aphids are most common group of vectors for the several viral diseases as, Alfalfa mosaic virus, Bean common mosaic virus, Calotropis ringspot mosaic virus, Cauliflower mosaic virus, Citrus tristeza virus, Citrus woody gall virus, Cowpea (aphid-borne) mosaic virus, Cucumber mosaic virus, Garlic mosaic virus, Green gram mosaic virus, Infectious chlorosis of banana, Leaf crinkle of sunflower, Lily symptomless virus, Muskmelon yellow stunt virus, Onion yellow dwarf virus, Papaya ringspot virus, Passion fruit Sri Lankan mottle virus, Pepper veinal mottle virus, Potato leaf roll virus, Potato virus, *Solanum trovum* mosaic virus, Sri Lankan passion fruit mottle virus, Sugarcane mosaic virus, Sweet potato feathery mottle virus, Turnip mosaic virus, Watermelon mosaic 1 virus, Watermelon mosaic 2 virus, Yam mosaic virus, Sunflower yellow blotch virus, Yellow vein mosaic virus, Zucchini yellow mosaic virus (Ebert and Cartwright, 1997, James *et al*., 2004).

Aphids Honeydew

Aphids feed on the phloem sap of plants, and are the most common honeydew (sweet excretory product) producing insects. While aphid honeydew is primarily considered to comprise sugars and amino acids, its protein diversity has yet to be documented. On the investigation of the honeydew proteome from the aphid using a two-Dimensional Differential in-Gel Electrophoresis demonstrating that aphid honeydew also represents a diverse source of proteins. The protein diversity of aphid honeydew originates from several organisms (the host aphid and its microbiota, including endosymbiotic bacteria and gut flora). Honeydew is also the keystone on which ant-aphid mutualism is built (Sabri *et al*., 2013). Ants may guard and care for aphids in return for the honeydew they produce. Ants protect aphids from weather and natural enemies and transfer them from wilted to healthy plants. In this way the ants ensure their source of honeydew, which they use as food. Ants obtain honeydew by stroking, or "milking," the aphids (Shik, 2014).

Alate production

There are two forces proposed as triggers for alate production in *A. gossypii*: nutritional factors and crowding. Starved nymphs from apterous parents resulted in 13% alates versus 0.4% from unstarred nymphs. However, starvation of nymphs from alate parents resulted in no increase in alate formation. A similar result was also reported for starved parents, where starved apterous parents produced more alate progeny than well-fed apterous parents (23% versus 2%, respectively) and there was no increase in alate formation by starved alate parents. Nutritional factors from other sources can affect *A. gossypii* development. In considering the possible role of aphid-borne plant viruses, the survival of the virus is dependent on having an efficient aphid vector, and the most efficient vector is alate. Therefore one might expect that a virus would promote conditions favouring alate production in the aphid. Alate production in the melon aphid-courgette-Zucchini yellow mosaic virus system appeared to increase on infected plants. Blua and Perring (1992) decided that nutritional factors are the cause for increased alate production. To further support the argument that the cause might be nutritional, it has been shown that aphid infestations on *Solanum integrifolium* changes peroxidase, esterase and protein content of the plant in proportion to the level of infestation (Owusu *et al*., 1994). This shows a change in plant nutrient content associated with aphid density which might form a chemical link between nutrition and alate production. Additional factors which influence alate production include crowding and type of parent (apterous or alate) and the possible effects of light and temperature (Guldemond *et al*., 1994).

Host plant and behaviour

Flight is the beginning of the dispersal phase in the aphid life cycle. It begins with the pre-flight period (from moult to flight) which lasted from 1 to 31 hours with most activity 10-24 hours after moult from colonies reared on *Veronica persica*. The general pre-flight period increased from 10 to over 70 hours with decreasing temperatures from 28 to 12°C. Adults flew from about sunrise to early afternoon, but a few individuals continued to fly after dark. With first light at 06.00 h, and last light at 19.30 h, no flight was detected from 23.00 h to 07.00 h. In laboratory colonies, the flight period lasted from 1 to 4 days (Nozato, 1990). Orientation to host plants was significant at 6 hours after wing development, but was highly significant after 24 hours. Alates were able to distinguish between different plants; *Cucurbita pepo* and *Thunbergia laurifolia* were attractive, and were common hosts for *A. gossypii* in Cuba. The occasional host *Hibiscus rosa-sinensis* was neither attractive nor repellent, and the non-host plant *Lantana camara* was repellent. *L. camara* found in locations other than Cuba has been recorded as a summer host of *A. gossypii*. This apparent contradiction is due to differences in aphid populations and relationship with host plant found in differing geographical areas (Zepeda *et al*., 2017).

Study area

Garhwal region of Uttarakhand is located in the North Hill part of India, between latitude from 30° 15' N to 31˚-- 28′ North and Longitude 79° 15' to 81˚- 02′ East. Garhwal is the western region and administrative division of Uttarakhand (Figure 2). Lying in the Himalayas, it is bounded on the north by Tibet, on the east by Kumaon region, on the south by Uttar Pradesh state, and on the northwest by Himachal Pradesh state. It is characterized by two types of climate, sharply differentiated in the plains and the mountainous regions with lush green forest and landscape quite rich in natural resource. GPS Garmin-US was used for latitude, longitude and altitude during field survey. Aphids were collected from different sites and altitude and identified by the method (Blackman and Eastop, 2000; Martin, 2008). A survey conducted for Aphid diversity at different crops and altitudes in the Garhwal region of Uttarakhand. Species identified from different crops were as follows (Figure 3):

Figure 2. Map of Aphids diversity and ecology in Garhwal region of Uttarakhand.

Cotton aphid (*Aphis gossypii*)

The melon, or cotton, aphid is green to black. In warm climates live young are produced all year, while in cooler areas there is an egg stage. Among the dozens of possible hosts are melon, cotton, and cucumber. It is usually controlled by naturally occurring parasites and predators. *Aphis gossypii* is small, adaptable, easily spread, with a rapid reproductive rate, and the ability to cause serious plant injury in isolated communities. *Aphis gossypii* Glover is highly polyphagous and is now considered to consist of distinct phenotypes and genotypes, both holocyclic and anholocyclic, that vary with respect to their ability to reproduce and food preferences on different host plants. Plants belonging to following families are highly infested: Asteraceae, Cucurbitaceae, Fabaceae, Lamiaceae, Malvaceae, Polygonaceae, Rosaceae and Solanaceae (Singh *et al*., 2014).

Taxonomically, *A. gossypii* is difficult to separate from *Aphis frangulae.* (Strogani, 1984) regarded *A. gossypii* as a sub-species of *A. frangulae*. Cotton-melon aphid *Aphis gossypii* is a fine life system to study the evolution of feeding habit because of the short life history, various reproductive modes, and wide host plant range (Liu *et al*., 2005). Following characteristics were used to identify *A. gossyppiii*. The cornicles or siphunculi are uniformly sclerotized from tip to base, and darkly pigmented. They are longer than the cauda and gradually taper towards the apex with a small dilation there. The dorsal abdominal segments are uniformly sclerotized and unpigmented. *A. gossypii* reared near the colour transition temperature often have a blotchy appearance with some parts greenish and other parts more yellow. The cauda usually have 4-7 hairs and are paler than the cornicles. Stidulatory apparatus is absent. The antennal tubercles are weakly developed. The terminal process is more than twice the length of the last antennal segment, but less than 3.5 times as long (Singh and Srivastava, 1989).

Cotton aphid (*Aphis gossypii*)

Myzus persicae (Sulzer) nymp

Rose aphid (*Macrosiphum rosae*)

Pea aphid (*Acyrthosiphon pisum*)

Potato aphid (*Macrosiphum euphorbiae*)

Aphis spiraecola

Aphis craccivora (cowpea aphid/ Ground nut aphid)

Cabbage aphid *(Brevicoryne brassicae)*

Figure 3. Selected aphids species of Uttarakhand.

Black bean aphid (*Aphis Fabae*)

Green citrus aphid (*Aphis spiraecola*)

Figure 3. Continued...

A. gossypii is a small aphid. Adults range from just under 1 - 1.5 mm in body length. The minimum diameter is just over 0.34 mm. This is indicated by the fact that a screen with a mesh diameter of under 0.34 mm is able to exclude *A. gossypii* (Bethke and Paine, 1991). Other characteristics combined can provide greater separation between instars especially under constant temperatures. *A. gossypii* can range in colour from yellow to very dark (almost black) green. The smaller yellow form occurs during warmer summer conditions. The green form is larger and occurs during cooler spring and autumn temperatures, and uncrowded conditions. Colour morphs are able to produce progeny of another colour morph. Host plant can also influence aphid colour (Ebert and Cartwright, 1997). The initial symptom of *A. gossypii* attack is a yellowing of the leaves. As populations continue to rise, aphids move to younger leaves, stems and flowers (sepals mostly). Plants become covered with a black sooty mould which grows on the honeydew excreted by the aphid. At very high densities, *A. gossypii* is able to kill its host. *A. gossypii* exhibits an anholocyclic life cycle, while in cooler areas it exhibits either a heteroecious or autoecious holocyclic life cycle (Zhang and Zhong, 1990). The heteroecious cycle involves a migration from a winter host to a summer host in the spring and a return to a winter host in the autumn for laying eggs. Significant differences were found in birth rates of *A. gossypii* reared on cotton, watermelons and groundnuts (Ekukole, 1990). The optimal temperature for reproduction is 20 - 25°C when the aphid can produce an average of 2.8 nymphs per day (Akey and Butler, 1989). The most important impact *A. gossypii* has on world agriculture is through its ability to transmit plant viruses. *A. gossypii* on okra infected with Yellow-vein mosaic virus did not reproduce as fast as those on healthy okra.

Green peach aphid (*Myzus persicae*)

The green peach aphid (*Myzus persicae*), also called the spinach aphid, is pale yellow-green with three dark lines on the back. The life cycle involves two hosts. The female reproduces parthenogenetically during summer and produces sexual males and females in autumn. It is a serious pest, transmitting many plant mosaic diseases. Adult wingless parthenogenetic females are oval-bodied, 1.2 - 2.1 mm in body length, of very variable colour; whitish green, pale yellow green, grey green, mid-green, dark green, pink or red. Apart from genetically determined colour variation, any one genotype will be more deeply pigmented green or magenta in cold conditions. Immature stages are quite shiny, but adults are less so. Winged morphs have a black central dorsal patch on the abdomen. Immatures of the winged females are often pink or red, especially in autumn populations, and immature males are yellowish (Blackman and Eastop, 1984). *Myzus persicae* is probably of Asian origin, like its primary host plant (*Prunus persica*) but now occurs everywhere in the world except where there are extremes of temperature or humidity.

Myzus perssica inspect for curled leaves, in which colonies develop in early spring. Monitoring is important in field crops, but *M. persicae* transmits viruses of crops such as sugar beet and potato at low densities, and is therefore difficult to detect on the crop before the damage is done. Suction and yellow traps are the most efficient way to detect first migration of winged aphids into the crop. Networks of suction traps have been developed to monitor migrating aphids, for example, the Rothamsted Insect Survey in the UK and AGRAPHID in France (Hulle *et al*., 2000). It is not clear whether the sexual part of the life-cycle is completed on species other than *P. persica* and *P. nigra. M. persicae* is highly polyphagous on summer hosts, which are in over 40 different families, including Brassicaceae, Solanaceae, Poaceae, Leguminosae, Cyperaceae, Convolvulaceae, Chenopodiaceae, Compositae, Cucurbitaceae and Umbelliferae. Summer hosts include many economically important plants in flowering stage, Post-harvest, Seedling stage, Vegetative growing stage. Effect of infestation depends greatly on host plant and transmitted viruses. Spring populations on peach cause severe leaf curl and shoot distortion. In potato, PLRV symptoms are leaf rolling and tuber stem necrosis. Ghosh and Verma (1990) reported apterous oviparous females of *M. persicae* first time from India, collected on *Prunus persica.*

A series of generations of wingless (apterous) and alate virginoparae are produced viviparously by thelytokous (all-female) parthenogenesis. Autumn migrants (gynoparae), migrate back to peach. Gynoparae will attempt to colonize a range of trees and shrubs, but the sexual part of the cycle is only completed on *Prunus persica* and close relatives. Gynoparae produce oviparae (mating females) that feed and develop on peach leaves. Plant nutrition is a factor in the induction of winged forms, along with temperature, but there is also a strong genetic component. *M. persicae* is relatively cold resistant. Howling *et al*. (1994) described mortality of aphids at various cold temperatures and their results suggested that an acclimatized overwintering population of *M. persicae* would persist without significant mortality after a period of 7-10 days with -5°C frosts each night. It is highly variable species; strains, races and biotypes have been distinguished by morphology, colour, biology, host-plant preference, ability to transmit viruses and insecticide resistance (Field *et al*., 1994). *M. persicae* has been shown to transmit well over 100 plant virus diseases, in about 30 different families, including many major crops. Direct feeding damage can result in stunting and reduced root weight, but populations on most crops do not reach levels causing obvious symptoms such as chlorosis or leaf curling, and the production of copious honeydew with associated sooty mould and direct damage on potatoes (Sexson *et al*., 2005). *M. persicae* is a major pest everywhere potatoes are grown. It is the most important vector of Potato leaf roll virus (PLRV). Yield losses in sugar beet due to beet yellows are more serious if infection occurs early in the season and can be up to 30-50%, with an increase also in the impurities present in the harvested sugar. On peach the aphid causes twisting of the young leaves and on nectarines, pitting on and discoloration of the young fruits (Barbagallo *et al*., 2007).

Corn root aphid (*Anuraphis maidi radicis*)

The corn root aphid is a serious pest dependent on the cornfield ant. During the winter, the ants store aphid eggs in their nests and in the spring carry the newly hatched aphids to weed roots, transferring them to corn roots when possible. The aphid stunts the growth of corn and causes plants to turn yellow and wilt. Corn root aphids also infest other grasses. The eastern spruce gall adelgid (*Adelges abietis*) produces pineapple-shaped galls 1 to 2.5 cm (0.4 to 1 inch) long composed of many cells, each containing about 12 aphid nymphs. The galls open in midsummer, releasing mature aphids that infect the same or another spruce. Infested branches often die, but individual trees vary in susceptibility. It appears as patches of yellow on the plant and may wipe out an entire field. Pale green adults have a dark green stripe down the back. Each female produces between 50 and 60 young per generation, and there are about 20 generations annually. It is controlled by parasites and insecticides and common in Uttarakhand.

Pea aphid

The pea aphid (*Acyrthosiphon pisum*) has two colour morphs, pale green and pinkish red. It overwinters on clover and alfalfa, migrating to peas in spring. The yellow bean mosaic virus it transmits is often responsible for killing pea plants. Each female produces 50 to 100 young in each of 7 to 20 generations a year. It is controlled by insecticides and weather conditions. It is also susceptible to natural predators such as ladybugs and to parasites such as the acrid *Allothrombium pulvinum.* The pea aphid's colour, which is determined by variations in genes that produce carotinoid pigments, may help it evade predators and parasites. Its ability to produce carotenoids is the result of a process known as horizontal gene transfer, in which the pea aphid acquired carotenoid genes from fungi tens of millions of years ago. Carotenoid production has been linked to energy (ATP; adenosine triphosphate) production in pea aphids. The development and mortality of juveniles and the life-span, age-specific fecundity and survivorship of adult aphids were recorded and used to construct life tables. The juvenile development period (from birth to adulthood) was longest at 11.9°C (16.8 days on cv. Scout and 16.2 days on cv. Sancho) and shortest at 26.7°C (8.5 days on cv. Scout and 8.8 days on cv. Sancho). On both pea varieties juvenile mortality was highest at temperatures above 19.6°C and lowest at 19.6°C. Highest cumulative juvenile mortality was recorded on cv. Scout at 26.7°C when only 9% of aphids survived from birth to reproductively mature adults. Fecundity rates were unaffected by temperature in the range tested on cv. Sancho but increased with increasing temperatures between 11.9 and 19.6°C on cv. Scout. These differences in life history parameters were reflected in the population growth (rm) of aphids on both pea cultivars which increased with increasing temperatures between 11.9 and 23.1°C on cv. Sancho and 11.9 and 19.6°C on cv. Scout, declining thereafter. Population growth was consistently greater at all temperatures for aphids reared on Sancho than those reared on Scout.

The potato aphid *(Macrosiphum euphorbiae)* begins as black eggs on rose plants, which hatch into pink and green young that feed on rosebuds and leaves. In early spring they migrate to potatoes, which are the summer host. One generation occurs every two to three weeks. It is the carrier of tomato and potato mosaic virus diseases that kill vines and blossoms. Many aphid species are monophagous. About 10% of species feed on different plants at different times of year. A new host plant is chosen by a winged adult by using visual cues, followed by olfaction using the antennae; if the plant smells right, the next action is probing the surface upon landing. The stylus is inserted and saliva secreted, the sap is sampled, the xylem may be tasted and finally the phloem is tested. Aphid saliva may inhibit phloem-sealing mechanisms and has pectinase that ease penetration. Data showed aphids consume more xylem sap than expected and they notably do so when they are not dehydrated and when their fecundity decreases. Plant sap is an unbalanced diet for aphids, as it lacks essential amino acids, which aphids, like all animals, cannot synthesise, and possesses a high osmotic pressure due to its high sucrose concentration. Essential amino acids are provided to aphids by bacterial endosymbionts, harboured in special cells, bacteriocyte. Potato aphid is common in potato cultivating zone of Uttarakhand.

Rose aphid

The Rose aphid (*Macrosiphum rosae*) is large and green with black appendages and pink markings. It is common on its only host, the cultivated rose. Natural predators are ladybird larva and aphid lions (lacewing larvae). Adult *Macrosiphum rosae* apterae are green or deep pink to red-brown. The antennae and sometimes the head are dark, as are the ends of the tibiae and femora. The abdomen may or may not have small marginal sclerites and antesiphuncular sclerites. The siphunculi are black and bent outwards and are reticulated on the apical 10-17%. They are about 0.27-0.41 times the body length and 1.9-2.4 times the length of the cauda. The cauda is pale yellow. The adult aptera of *Macrosiphum rosae* is 1.7-3.6 mm long. *Macrosiphum rosae* alatae have conspicuous black sclerites along the sides of the abdomen (see third picture above). They also have green and red colour forms. The rose aphid usually overwinters in the egg stage on rose bushes (its primary host), although in mild winters some adults may continue to reproduce parthenogenetically. In spring they colonise the young growth of rose, and produce large numbers of alates. These mostly migrate to their secondary hosts, teasels (Dipsaceae) and valerians (Valerianaceae). However, colonies can be found all summer on rose and the species is an important horticultural pest. *Macrosiphum rosae* has a worldwide distribution and common in Uttarakhand.

Rosy apple aphid

The rosy apple aphid (*Dysaphis plantaginea*) deforms fruit, producing “aphis apples.” Its feeding activity causes leaves to curl about it, providing some protection from insecticide sprays. The life cycle involves plantain plants as alternate hosts from which the aphid returns to the apple tree to deposit eggs in the fall. It also attacks pear, hawthorn, and mountain ash. It is often controlled by natural enemies, chiefly syrphid flies, lady beetles, lacewings, and parasitic wasps and by insecticides. The woolly apple aphid (*Eriosoma lanigerum*) lives on roots and may stunt or kill apple trees. Aphids have antennae with two short, broad basal segments and up to four slender terminal segments. They have a pair of compound eyes, with an ocular tubercle behind and above each eye, made up of three lenses (triommatidia). They feed on sap using sucking mouthparts called stylets, enclosed in a sheath called a rostrum, which is formed from modifications of the mandible and maxilla of the insect mouthparts. Most aphids have a pair of cornicles (siphunculi), abdominal tubes on the dorsal surface of their fifth abdominal segment, through which they exude droplets of a quick-hardening defensive fluid containing triacylglycerols, called cornicle wax and defensive compounds can also be produced by some species.

Mustard aphid (*Lipapis erysemi*)

Mustard aphids are small, soft-bodied, pearl-shaped insects that have a pair of cornicles (honey tubes) projecting out from the fifth or sixth abdominal segment. There are four nymphal stages (instars). Wingless, female, aphids are yellowish green, grey green or olive green with a white waxy bloom covering the body. The winged, female, adult aphids have a dusky green abdomen with dark lateral stripes separating the body segments and dusky wing veins. Male aphids are olive-green to brown in colour. Both nymph and adults suck the sap from leaves, inflorescence or the developing pods. As aphids become more numerous, leaves become puckered, and curled. Curling may occur for infested leaves and at advanced stage plants may wither and die. The aphid attacks generally in December and continues till March. The most favourable temperature is 20^0C. Cloudy and cold weather help in accelerating the growth of insects. Plants are infested at all the stages and is common in Uttarakhand and Uttar Pradesh.

Aphis craccivora

Aphis craccivora is a cosmopolitan polyphagous crop pest of legumes. Though there have been reports of sexual morphs, *Aphis craccivora* aphids are thought to be primarily anholocyclic, i.e., only reproducing parthenogenetically, in northern latitudes, dying off during the winter and recolonizing temperate areas via migration each season. The aptera of *Aphis craccivora* is dark brown with (usually) a very solid black shiny carapace from the metanotum to abdominal tergite *Aphis craccivora* populations have a reduced sclerotic shield. The longest hair on the third antennal segment is usually 0.5 - 0.6 times the basal diameter of that segment. Their siphunculi very rarely have any trace of constriction before the flange, and are 1.2 - 2.2 times the length of the cauda. The cauda has the distal part tapering and is 0.09 - 0.13 times body length. The body length is 1.16-2.3 mm.

Aphis spiraecola

Aphis spiraecola is a relatively small aphid. Alatae are 1.2-2.2 mm and apterae 1.2-2.2 mm, with largest body sizes. Its body colour is bright greenish-yellow or yellowish-green to apple-green. It has a brown head, mainly pale legs and antennae, but siphunculi and cauda that are dark-brown to black. Alatae have a dark-brown head and thorax, and a yellowish-green abdomen with dusky lateral patches on each segment. *A. spiraecola* has a diploid chromosome (2n=8). The species now has a worldwide distribution in temperate and tropical region (Swirski *et al*., 1991; Blackman and Eastop, 2000).

It is a moderately polyphagous species. Primary (winter) hosts are *Spiraea spp*. and *Citrus spp.* It has numerous secondary host plants, in well over 20 families, particularly in the Caprifoliaceae, Compositae, Rosaceae, Rubiaceae and Rutaceae. The aphid has a preference for woody plants of a shrubby growth habit. Citrus and apple are the most important crop hosts (Blackman and Eastop, 2000), although grapefruit is almost immune to attack (Bannerman and Roitber, 2014). The first small colonies on new citrus growth occur by early February. In hot weather, nymphs can grow into adults within 5-6 days, leading to rapid population growth. On average, one aphid deposits 30 nymphs. Up to 14 generations may be produced in one year. An increased proportion of winged forms are produced in response to both over-crowding and a deteriorating food supply. These alates migrate in search of fresh young hosts. In the autumn, fruit formation enriches the sap in favour of the aphid and populations start to build up again. In winter, in temperate areas, few adults survive. Sexual females (oviparous) in holocyclic populations of *A. spiraecola* release a sex pheromone and display typical leg-waving behaviour during its release. In laboratory-reared aphids, the pheromone composition was (+) -(4aS,7S,7aR) - nepetalactone and (-) -(1R,4aS,7S,7aR) - nepetalactol in the ratio of 6:1 to 8:1 (Hohn *et al*., 2003). *Aphis spiraecola* is mainly spread via the flight of winged forms. Aphids can also be carried on fruits and ornamental plants to new areas, where they may establish on host crops. Lacewing predators may be attracted to the aphid sex pheromone (Boo and Park, 2005).

Cabbage aphid *(Brevicoryne brassicae*)

The cabbage aphid (*Brevicoryne brassicae)* is small and gray-green with a powdery, waxy covering. It is found in clusters on the underside of leaves of cabbage, cauliflower, Brussels sprouts, and radishes. It overwinters as black eggs in northern regions but has no sexual stage in southern regions. When necessary, it can be controlled with the use of insecticides. The cooley spruce gall adelgid (*Adelges cooleyi*) causes formation of cone like galls about 7 cm (3 inches) long on the tips of spruce twigs. In midsummer when the galls open, adults migrate to Douglas firs to lay eggs. However, the life cycle may proceed on either spruce or Douglas fir. Control is by spraying with insecticide, removing galls before aphids emerge, and planting spruce and Douglas fir apart from each other. Monitoring of pest population and relative abundance of natural enemies is an important component of an area-wide pest control which overcome pesticide residue problem (Sarwar, 2009).

Cabbage is an excellent source of vitamin K, vitamin C, and vitamin B6. It is also a very good source of manganese, dietary fibre, potassium, vitamin B1, foliate and copper (Dias, 2012). A number of limiting factors have been attributed for low productivity of cabbage, among them, the chief constraint in the production of cabbage is damage caused by pest complex right from germination till harvesting stage listed 51 insect pests to damage cruciferous crops throughout the world. In India, a total of 37 insect pests have been reported to feed on cabbage. Among the insect pests, aphids alone cause 9 - 96 per cent reduction in yield (Singh and Sharma, 2012). These aphids are widely distributed throughout the world on all *Brassica* crops. Plant produced many volatile compounds which guide them towards their host. Owing to the high fecundity and short generation period, it can reach population densities much higher than the economic threshold levels of 50-60 aphids/10 cm top central twig of plant making them intractable to control. Continuous application of similar pesticides may increase pest resistance and out beak of secondary pests or resurgence (Kumar and Paul, 2017).

Black bean aphid (*Aphis Fabae*)

Aphis fabae is also called bean aphid. Adults of *Aphis fabae* can weigh from as little as 200 µg to as much as 1800 µg a remarkable range in size for a single species. An extensive range in size also occurs among the adults in other species of aphid. Small individuals result when aphids develop either under crowded conditions or on a mature host-plant; large aphids result when the nymphs are reared in isolation or on young or senescent host-plants. A small adult produces fewer nymphs and also smaller nymphs than average. When aphids are overcrowded or feed on host-plants of poor quality, many aphids reach maturity that might otherwise fail to mature because of the ability of the species to produce viable adults of a great variety of size, including very small adults. Global average surface temperature is predicted to increase by 1.5 to 4.5 °C by the end of the 21st century. Due to this increase, major variability in climatic conditions could occur which includes more frequent droughts and higher mid-summer temperatures (IPCC, 2013). These predicted climate changes are likely to affect species distributions, life-history traits, trophic interactions and ecosystem functions (Traill *et al*., 2010).

Control of aphid species

Aphids are important sentinels of climate change. Insect metabolism and physiology display a high degree of sensitivity to air temperature, humidity, photoperiodism with daily and seasonal cycles, small plant feeding insects are regularly exposed to high ambient temperature stress (Neven, 2000). Temperature most directly affects insects by altering behavior and metabolic rate and downstream cellular and physiological processes (Bale *et al*., 2009). Aphids have complex life involve many morphological distinct forms and parthenogenetic generation alternating with asexual generation, and in about 10% of species this is associated with host alternation (Foottit *et al*., 2008). Aphid pests occurs throughout the temperate region of the world, causes direct damage by sucking plants sap which affects growth and yield of the crops (Gulidov and Poehling, 2013). Many species of aphids are pests in agriculture, forestry and horticulture. Abiotic factors including temperature, relative humidity, rainfall and total sunshine greatly influence the population of insect pests (Sanchis *et al*., 2005). Numerous factors influence the physiology of water-deficit stressed plants and subsequently the performance of insect herbivores. Depending on plant species, cultivar and age, duration and severity of water-deficit stress and aphid species, aphid abundance may be affected positively negatively or remain unaffected (Rivelli *et al*., 2013). Water stress or enhanced, had an adverse effect or had no effect on aphid population growth, depending on the cultivar and watering regime. No difference was recorded in the population dynamics of *M. euphorbiae* feeding on Beef master tomato plants subjected to different levels of water stress. In the case of the cultivar Scintilla, live aphids were less abundant on stressed plants than on well watered ones. The initial peak in aphid numbers was higher on the water stressed plants than on the control and then decreased to lower numbers than on the control. There were no differences in the numbers of aphids infesting stressed and control plants and fewer aphids on stressed than on control plants (Showler *et al*., 2013).

The severe effects of UV-B radiation along with photosensitizer on larval development, mortality and offspring were studied (Kumar *et al*., 2019). Studies with adult have shown that UV-B radiation act as immuno suppressive agent to aphids. A significant increase in the incidence of UV radiation as an apparent consequence of a decrease in the ozone layer has been reported in Patagonia (Villafane *et al*., 2001). With daily and seasonal cycles, small plant feeding insects are regularly exposed to high ambient temperature stress. Temperature most directly affects insects by altering behavior and metabolic rate and downstream cellular and physiological processes (Bale *et al*., 2007). Exposure to solar UV radiation affect productivity, reproduction, development, increase the mutation rate in phytoplankton, macro algae, have drastic biological impacts, including detrimental effects on individual organisms as well as on ecosystems (Jokinen *et al*., 2005). Various facultative symbionts can also associate with the pea aphid, some being known to benefit host aphids under high temperature conditions, aphids and their symbionts are interesting models for studying the effects of temperature and UV stress farmers are not with the ill effects of chemical pesticides and still using most of the systematic and organic insecticides to control this insect pest (Ali and Rizvi, 2007). In laboratory experiments, low temperature promoted, while high temperature tended to suppress, the development of winged forms Temperature is both a selective pressure and a modulator of the diapause expression in insects from temperate regions. Thus, with climate warming, an alteration of the response to seasonal changes is expected, either through genetic adaptations to novel climatic conditions or phenotypic plasticity (Tougeron *et al*., 2017).

Conclusion

Thus, from the above discussion it was evidenced that aphid community play an important role in agricultural ecosystem in particular to Uttarakhand state of India. Now a days, the aphid communities are being affected by several natural and anthropogenic factors. However, aphid causes damage to the crops like mustard, cabbage, pea, potato, bean, lemon, cotton etc. and flowers like rose, lily, marigold etc. This chapter provided research oriented information about aphid diversity, ecology and inventory in the mountainous region.

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Chapter
[18]

Insect's diversification and their conservation strategies

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Abstract

In planet Earth, insects are the most dominant diverse and important group. The terrestrial diversity of insect is large as compare to insect live in other habitat. Insects possess an amazing diversity in morphological characters as well as in genetic diversity that's helps in survival in different environmental conditions. The great insect diversity is indeed an intrinsic part of the Earth's ecosystem and they are what make the ecosystem. Thus, the diversity and ecological importance of insects make them very valuable for studies of biodiversity. Similarly, Insects have great potential for understanding ecosystem and to measure the ecosystem health but the limited knowledge and resources increase the difficulty of work on insect biodiversity The conservation of insect biodiversity is very important for the investigation of relation between climatic factors and insect diversity with respect to impact of human as well as increasing globalization. The limited research study on global insect diversity is harmful in advance study and research field with respect to advance evolutionary insect ecology. This book chapter explores the conservation of various species with their diversity. It includes assessments of insect's population as compare to bio-ecology changes.

Keywords Conservation, Community ecology, Evolution, Insect, Species abundance

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Introduction

Insects are the most dominant creatures of earth and they help in pollination, seed dispersal, maintain soil fertility, control population of other organisms and play an important role in foundation of ecosystem. Some insects are beneficial and some are referred as pests, others are beneficial to human being. About 80 to 95% of insect species were identified and approximate 30 million insect species found in tropical region (Stork, 2007). Insects are evolved at the time of Devonian period (200 million years ago) and it is the largest class in animal kingdom consist 29 orders. First they appeared in the Ordovician period, approximately 480 million years ago (Singh and Sidhu, 2015). However, most of the species of insects are unknown about their behaviour that causes the insect diversity i.e. faced with habitat degradation, species extinction and a decline in the natural enemies of harmful pests and these problems are due to the expansion of agriculture, urbanization, industrialization, pollution, mining, tourism, introduced species, hunting and the illegal trade in endangered species. The great insect diversity is indeed an intrinsic part of the Earth's ecosystem and they are what make the ecosystem (Samways, 1994). Thus, the diversity and ecological importance of insects make them very valuable for studies of biodiversity. Similarly, Insects have great potential for understanding ecosystem and to measure the ecosystem health but the limited knowledge and resources increase the difficulty of work on insect biodiversity (Danks, 1996). The functional significance of insects are enormous, owing to the large number of individuals and great intra-and interspecific variety as well as insects play a key role in providing numerous irreplaceable services, many of which are critical to human survival and wellbeing. Yet, most insects are non-charismatic at best and perceived as pests at worst. As such, they receive little attention, attracting few resources for monitoring and conservation (Krause and Robinson, 2017). Lack of human appreciation coupled with the general disregard and dislike of insects, is an enormous perception impediment to their conservation. This impediment coupled with the taxonomic impediment, must be overcome for realistic biodiversity conservation. As it is not possible to know all the species relative to the rate at which they are becoming extinct, it is essential to conserve many biotopes and landscapes as possible. These would be for typical species and communities, as well as for endemic sinks. Currently insect conservation has a foothold in six interconnected themes such as philosophy, research, psychology, practice, validation and policy, the latter of which makes the framework for action (Samways, 2018). A common challenge in insect species conservation and management is to manage species belonging to various orders particularly in relation to life-cycle interventions. Only about 7700 species having been evaluated for the Red List and only 1% of insect species were described (Cardoso *et al*., 2011; Foottit and Adler, 2017).

Nevertheless, species management may be a tool to be explored further in insect conservation. It is also essential to preserve species dynamo areas as insurance for future biodiversity of insect. The preserved areas of insects must also be linked by movement and gene-flow corridors as much as possible. However, insect biodiversity faces the same ecological threats as all other biodiversity (Hook, 1997). Insects are covered under many international conventions, including the pivotal Convention on Biological Diversity. Insects are also being included in many National Biodiversity Action Plans and

Agri-Environment Schemes. This goes hand in hand with raising public awareness of the plight of insects (Samways, 1994). Ecological restoration involves so many biotic and abiotic interactions in even the simplest of communities, that productiveness under all potential conditions is virtually unattainable. Instead, there should be strong focus on the preservation and conservation of as many and as large as possible, pristine and near-pristine unique and typical landscapes as soon as possible.
The book chapter explores the wide variety in types, number of insect species and their evolutionary relationships. Insect's biodiversity help to meet the needs of rapidly expanding human population and also examine the consequences that increased loss of insect species in the world.

Insects and their importance for ecosystem

Insects and related arthropods structure is quite 50 percent of the known animal diversity. Over the last 400 million years, the amounts of insect families have been steadily rising. There are 1.4 millions species of insects described in the scientific literature which is 80% of life currently recorded on earth. The estimation indicates that there may be as many as 30-50 million species of insects. This perceives terrestrial orthopaedical groups which is 97% of global diversity (Erwin, 1982; Kulshrestha and Jain, 2016). The world of insects is amazing and diverse. No other group of animals has developed such an enormous array of species. We encounter them within the widest range of shapes and sizes. They may be as big as your hand or microscopically small. All of them have three pairs of legs. Hence the scientific name "Hexapod" or "six feet", the zoological subphylum that covers insects along with a few other, less-common creatures. The description of insects and their colourful body patterns have initiated prominent contributions to our art, literature, culture and offer great educational tools (Pyle and Opler, 1981). Insects are often confused with other creepy-crawlies, such as mites, ticks and woodlice. The same is true of centipedes and millipedes, although their names ("hundred" or "thousand feet") indicate that they cannot possibly be insects. Spiders are also sometimes lumped together with insects though they neither have eight legs nor are crabs, which have ten legs (including a pair of pincers), counted as hexapods. Apart from all having six legs, insects have various other features in common. Their bodies consist of three segments are the head with the mouth parts and thousands of individual lenses clustered into compound eyes, the thorax that bears three pairs of legs and in flying insects, the wings and the abdomen, which houses the digestive and they have reproductive parts on their abdomens (Snodgrass, 1935; Gullan and Cranston, 2020). Insects have no skeleton and their bodies are encased within a thin, horny layer of chitin that protect them from water and give their body stability along with flexibility. Insects don't have lungs, they breathe via a system of tubes and sacs referred to as trachea that run throughout the entire body (Snodgrass, 1935; Gullan and Cranston, 2020). Insects pass through several stages of development, some of which may make completely different demands on their habitat – both in terms of their structure, features, and interrelationship and in their food sources. Most insects lay eggs that hatch and pass through several larval stages, perhaps along with a pupal stage (Snodgrass, 1935).

Some types of insects including dragonflies, crickets and bugs do not undergo a pupal stages such as bumblebees, butterflies and beetles must pupate to produce an adult (Snodgrass, 1935).Within this general plan there's an outsized amount of variation and that they are inter alia, predators, herbivores, decomposers, and parasites representing a wider range of life histories than the vertebrates.

Insects pollinate flowers and they help in reproduction in majority of plants such as *Apis meliffera* L. (European honey bee) is liable for the pollination services in majority of crops (Getanjaly *et al*., 2015). Non-Apis bees are also important pollinators of crops, examples of managed non-Apis species include bumble bees, *Bombus impatiens Cresson* (Hymenoptera: Apidae) managed for cranberry (*Vaccinium* spp.) and greenhouse tomato (*Solanum lycopersicum* L.). Bees are considered the foremost effective insect-pollinator of most plant species but other insects are recognized for his or her contribution to pollination such as flower visiting flies (Diptera) are pollinators of several crops including carrot (*Dacus carota* L.), mustard (*Brassica* spp.), leek, (*Allium ampeloprasum* L.), almond (*Prunis dulcis*) and weevil *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) play great role in pollination of Oil palm (Getanjaly *et al*., 2015). in temperate region about two third of all the plant species depend on insects for pollination and the most important pollinators are bees, beetles, butterflies and flies. There are many insects found on agriculture land which are not threat to the crop production but beneficial to the farmers in different aspects as natural enemies, pollinators, productive insects, scavengers, weed killer and soil builders (Schoonhoven *et al*, (2005). Beneficial insects provide regulating ecosystem services to agriculture like pollination and therefore the natural regulation of plant pests (Getanjaly *et al*., 2015). Similarly, insects in terrestrial ecosystem plays specific role such as nutrient cycling, seed dispersal, bioturbation, pollination and pest control (Jankielsohn, 2018).

In the insect orders Odonata (dragon flies) and Neuroptera (lacewings and ant lions) all the insect species are predators while an outsized percentage of species within the orders Hemiptera (bugs), Coleoptera (beetles), Diptera (flies) and Hymenoptera (wasps, bees and ants) are predators, either as larvae or in both larval and adult stages (Table 1). The biodiversity of insects found in natural ecosystem plays an important role in sustainable agricultural production and food security (Jankielsohn, 2018).There are various parisitoids in the order Hymenoptera that parasitizes adults, larvae or eggs of other insects. For instance, *Aphytis lingnanensis* parasitizes scale insects, *Aphelinus asychis*, *Aphelinus varipes*, *Diaeretiella rapae*, *Aphidius colemani*, *Aphidius matricariae* and *Aphidius ervi* parasitizes cereal aphids and Trichogramma parasitic wasps attack Lepidopteran eggs (Getanjaly *et al*., 2015). Herbivorous insects with the potential of becoming pests are under natural control by insect predators and parasitoids (Van-Lenteren, 2012; Jankielsohn, 2018). Biotic communities are vital for providing ecological functions and ecosystem services (Naeem *et al*., 2012). As a dominant sort of animal biomass and life on earth, insects represent many various tropic niches and a good range of ecological functions in their natural ecosystem including herbivores, carnivores and detritus feeding.

Table 1. List of Beneficial insect or invertebrate (Getanjaly *et al*., 2015)

Group	Beneficial insect or invertebrate	Pest attacked
Beetles	Red and Blue beetles (*Dicranolaius bellulus*) Green carab beetles (*Calosoma schayeri*) Green soldier beetles (*Chauliognathus pulchellus*)	Aphids, mites, thrips, mealy bugs, moth eggs including *Heliothis* spp. and larvae.
Bugs	Bigeyed bugs (*Geocoris lubra*) Brown smudge bugs (*Deraeocoris signatus*) Damsel bugs (*Nabis kingbergii*), Glossy shield bug (*Cermatulus nasalis*) Pirate bug (*Orius spp.*) Apple dimple bug (*Campylomma liebknectic*) Spined predatory shield bug (*Oechalia*) Broken backed bug (*Taylorilygus pallidulus*)	Aphids, Diamondblack moth, eggs of and larvae of *Heliothis* spp., cut-worms (*Spodoptera litura*), false loopers
Lacewings	Green Lacewings (*Mallada signatus*) Brown Lacewings (*Micromus tasmaniae*)	Aphids, moth larvae and eggs, whitefly, thrips, mites and mealy-bugs.
Caterpillar (Parasitoids)	Banded caterpillar parasite (*Ichneumon promissorius*) Two-toned caterpillar parasite (*Heteropelma scaposum*) Sorghum midge parasites (*Eupelmus australiensis*)	Heliothis and other moth larvae Sorghum midge Heliothis, looper, armyworm, grasshopper and other larvae
Helicoverpa Egg Parasitoids	*Trichogramma chilonis*	Helicoverpa and Lepidoptera
Whitefly Parasitoids	*Encarsia formosa*	Whitefly
GVB (Green Vegie Bug) egg Parasitoids	*Trissolcus basalis*	Green vegetable bug

Insects are most abundant in terrestrial ecosystem and display a good variation among species in almost any aspect of their biology (Gullan and Cranston, 2020). Due to the massive number of insects and great intra-and interspecific variety, the functional significance of insects is giganticand plays an important role as a key component in diverse ecosystem (Samways, 1993; Kim, 1993). Since insects are mostly perceived as pests or potential pests. This ecological importance of insects often goes unnoticed. The main ecological functions of insects in ecosystem are ecosystem cycling, pollination, predation/ parasitism, and decomposition. Insect herbivores change the quality, quantity, timing of plant, detritus inputs and may potentially have large effects on ecosystem cycling. However, insect herbivory increased plant abundance due to greater availability (Mattson and Addy, 1975; Belovsky and Slade, 2000). Insect herbivores are therefore important drivers of ecosystem process by transforming living plant biomass into grass, green fall, and through fall should drive a big fraction of above-ground to below ground nitrogen and phosphorus fluxes across entire ecosystems (Hunter, 2001; Metcalfe *et al*., 2013). Ground beetles are also commonly used as bio-indicators for changes in environmental conditions. Thanks to their sensitivity to habitat change and since carabid studies are being highly cost-efficient (Rainio and Niemela, 2003). Hymenopteran and Coleopteran predators and parasitoids can help in pest control by feeding on pest species such as caterpillars or Hemiptera. Soil insects such as dung beetles and termites assist in soil fertility by their transformation, bio-turbation decomposition and by assisting nutrient cycling (Huffaker, 1959; Stork and Eggleton, 1992; Griffiths *et al*., 2019; Ulyshen, 2015) (Table 2). Termites in the tropic have a role somewhat analogous to temperate earthworms and have a similarly high biomass especially on wet acid soils and their contribution to ecosystem services have been valued at47 billion dollar a year (Jouquet *et al*., 2011; Losey and Vaughan 2006). Wilson (1987) has mentioned invertebrates generally with some justification, because the "little things that run the world".

Global biodiversity and species richness of insects

Insects are an immensely successful biological group, with possibly two to ten species on Earth today. Less than 10% of these have scientific names. Although insects at the family level have survived various major impacts over the last 100 million years, it's the specialists that died out during the mass extinction event at the end of the Cretaceous. Great insect diversity is indeed an

Table 2. List of ecosystem services provided by insects (Eggleton, 2020).

Order	Ecosystem service	Feeding Guild	Examples
Hymenoptera	Biological control	Predators	Formicidae (ants) and Vespidae (wasps)
Hymenoptera	Biological control	Parasitoids	Ichnemonidae, Braconidae, Chalcidoidea
Hymenoptera	Pollination	Herbivores	Mostly Apidae (bees)
Hymenoptera	Seed dispersal	Scavengers	Formicidae (ants)
Hymenoptera	Bio-turbation	scavengers	Formicidae (ants)
Coleoptera	Biological control	Predators	Carabidae (ground beetles) and Coccinellidae (ladybugs)
Lepidoptera	Pollination	Herbivores	Moths
Diptera	Animal decomposition	Scavengers	Many families
Blattodea	Plant decomposition	Decomposers	Termites, dung beetles and weevils
Blattodea	Bio-turbation	Decomposers	Termite constructions

intrinsic part of the Earth's ecosystem (Samways, 1994).Although evidence suggests that a lot of insect specialists died out at the top of the Cretaceous, most have survived up to many geological events over the previous couple of many years. This is now changing with the human impact estimated to be threatening the survival of one fourth of all insect species. Insects appeared first in the Ordovician, approximately 480 million years ago at approximately the same time when the first land plants evolved and insects were the first animals to evolve flight as well as they are dispersed and diversified across most of the continents (Condamine *et al*., 2016). However, evidence for the earliest case of terrestrial arthropod like termite from the early Cretaceous (Lacasa-Ruiz and Martinez-Delclos, 1986). Moreover, some cycads belong to Mesozoic era (Norstog, 1987) and the several groups of blood-sucking insects from order Diptera occur during the period of Jurassic Cretaceous and Paleozoic (Kalugina and Kovalev, 1985; Boudreaux, 1987) (Table 3). Their evolution of a plant feeding habit led their massive diversification (Snodgrass, 1935; Mitter *et al*., 1988). They are defined as a category of class Insecta and splits into some 29 orders. These orders can split into three groups based on their development pattern. Some are holometabolous with complete metamorphosis i.e. egg, larva, pupa, adult and others are hemimetabolous with incomplete metamorphosis i.e. nymphs and adults. There are some wingless insects that are ametabolous i.e. no distinction between larvae and adult, no nymphs

Table 3. Fossil history of major insect orders (Boudreaux, 1987; Gullan and Cranston, 1996)

Order	Earliest fossils	Million years ago
Archaeognatha	Devonian	390
Thysanura	Carboniferous	300
Odonata	Permian	260
Ephemeroptera	Carboniferous	300
Plecoptera	Permian	280
Phasmatodea	Triassic	240
Dermaptera	Jurassic	160
Isoptera	Cretaceous	140
Mantodea	Eocene	50
Blattodea	Carboniferous	295
Thysanoptera	Permian	260
Hemiptera	Permian	275
Orthoptera	Carboniferous	300
Coleoptera	Permian	275
Strepsiptera	Cretaceous	125
Hymenoptera	Triassic	240
Neuroptera	Permian	270
Siphonaptera	Cretaceous	130
Diptera	Permian	260
Trichoptera	Triassic	240
Lepidoptera	Jurassic	200

Table 3. Fossil history of major insect orders (Boudreaux, 1987; Gullan and Cranston, 1996)

Order	Common name	Feeding habit	Numbers of species
Blattodea	Cockroaches, termites	Detritivores	5,710
Coleoptera	Beetles	Various	392,415
Dermaptera	Earwigs	Detritivores	1,982
Diptera	True flies	Various	160,591
Ephemeroptera	Mayflies	Aquatic predators	3,281
Hemiptera	Bugs	Herbivores/predators	104,165
Hymenoptera	Bees, ants, wasps	Predators/herbivores	152,677
Lepidoptera	Butterflies, moths	Herbivores	158,570
Mantodea	Mantises	Predatorsc	2,447
Neuroptera	Net-winged insects	Predators	5,937
Odonata	Dragonflies, damselflies	(Aquatic) predators	6,650
Orthoptera	Grasshoppers, crickets	Herbivores	24,481
Phasmida	Stick insects	Herbivores	3,270
Plecoptera	Stoneflies	Aquatic herbivores	3,930
Psocodea	Booklice, true lice	Parasites/detritivores	10,746
Siphonaptera	Fleas	Parasites	2,086
Thysanoptera	Thrips	Herbivores	6,157
Trichoptera	Caddisflies	Aquatic predators	15,233

with secondarily wingless insects and not ametabolous (Snodgrass, 1935). The largest of those orders are all holometabolous: Lepidoptera (butterflies and moths), Coleoptera (beetles), Hymenoptera (bees, ants, and wasps), and Diptera (true flies) (Eggleton, 2020) **(**Table 4).

Class Insecta are extremely large groups having more than a millions of species. At present the total number of living species of insects is 5.5 million and they are the most taxonomically intractable of animal classes and there are many an identified species (Stork, 2018; Gaston, 1994). Similarly, order coleoptera has the largest number of described species (Roskov *et al*., 2020). However, insects are within the largest group of arthropods and leave every other group seeming relatively small but they showed large proportion of global diversity across the entire world's biota. Biological diversity is one of the most fascinating evolutions by natural selection producing different varieties of species (Kulshrestha and Jain, 2016). However, the success of insects have been due to their versatile methods of feeding, their ability to fly and locate their food sources, sometimes over many kilometres. Insects are extremely diverse and they have great potential for understanding ecosystem but the limited knowledge and resources about incest increase the difficulty of working on insect biodiversity (Danks, 1996; Finnamore, 1996; Spellerberg and Fedor, 2003). Species richness in trees of insects may serve as the best proxy for overall biodiversity in tropical forests. Crucial suppositions they made were that each of the 50,000 tree species of insects are in the world and out of them beetles represent 40% of all insect species. The canopy is rich in insect species as the ground species (Novotny, 2002).The other estimation showed dramatic losses of insects in the tropical rain forests which are home to at least half of all insect species that are found (Pennington *et al*., 2015). There is much estimation of extinction rates such as 11, 200 species of insects have gone extinct since 1600 and that possibly half a million insect species will go extinct in the next three centuries (Samway, 1994).

Conservation and their management for insect's diversity

The conservation of biodiversity has become one of the most important challenges on our planet. According to the beneficial components of insects as biological resources with effective control, many national strategies, legal actions and capacity-building activities have been developed or implemented (Danks, 1996). These efforts work towards the goal of insect diversity conservation and understanding the extent of insect diversity that is one of the major challenges in modern ecology. Insects have important economic roles, supporting and providing livelihoods for numerous people from the silk trade to beekeeping and the pollination of most of our fruit and a range of other agricultural produce. However, concern for declining insect population has been voiced since the first half of the 19th century and the historical aspects of insect conservation have been reviewed elsewhere (Pyle and Opler, 1981). The present momentum began in the 1960's, legislative measures were taken in the 1970's and being strengthened in the 1980's and1990's.The insects are responsible for many processes in the ecosystem and its loss can have negative effects on entire community. It is suggested that conservation of natural resources and biodiversity have become an urgent issue in recent years for attaining an environmentally sustainable future. While a lack of data has historically excluded the use of many taxa as possible indicators (Choudhary and Ahi, 2015; Samways, 1994).Insect conservation in the twenty-first century can be seen against six inter-related themes which are as follows:-

- Philosophy (establishing the ethical foundation)
- Research (the finding out),
- Policy (the framework for action),
- Psychology (understanding how human engage in insect conservation action)
- Practice (implementation of action)
- Validation (establishing how well we are doing at conserving insects).

We will now interrogate these themes in more detail. We do this against a background of species, landscape, national and global operational levels so as to move quickly to save the current insect diversity on Earth (Samways *et al*., 2020). For insect's conservation, this research is about finding new and effective ways for maintaining insect's diversity, insect species, and insects population. As insects are embedded in the ecological fabric around them, we need to understand it if we have to provide realistic insect conservation solutions. We research the optimal environmental conditions that enable insect's survival. These environmental conditions may be abiotic, such as temperature regimes, fire frequencies and intensity, rainfall patterns and intensity, insolation, elevation, rockiness, water, pH, dissolved oxygen as well as contaminants, pollutants, pesticides, and many others. Insect's community conservation and restoration have been identified as important yet difficult tasks (Arenz and Joern, 1996). International agreement is combined in the Convention on International Trade in Endangered Species of World Fauna and Flora (CITES), which controls and monitors import and export of listed species. By virtue of their huge abundance and great variety, insects are major player's in many ecosystem processes with keystone roles and largely maintain terrestrial ecosystem. However, the highest density of biodiversity research occurs in temperate climates, markedly in Western Europe (Titley *et al*., 2017). Similarly, 85% of insect species are found in the tropics and south temperate regions (Stork, 2018). Global monitoring programs are not implemented and unbiased data are not available. Land management and land protection are recognised as the most relevant conservation measures for the global preservation of insects across regions and taxa. Taking a landscape perspective to protection and management of insect biotopes is in fact one of the most effective ways to protect countless taxa, their unique ways of life, evolutionary history and complex networks (Samways *et al*., 2020). International Union for the Conservation of Nature (IUCN) species assessments, particularly regarding insects, almost invariably depend on expert scientific judgments as one of the sources of information that is used to measure our progress towards global biodiversity conservation goals. However, National parks and reserves must be adequately protected and must not be eroded by financial interests even during times of recession. The globally recognized list provides just not only an inventory of the world's species and their threat status, but also gives suggestions for conservation action. It does this through the activities of a network of specialists on various taxonomic groups. The concept based on marine animals like whale or weasel is raised considerably automatically (Cardoso *et al.,* 2011). However, for insect species- Red listing is that group which is so precious. Today, about 7700 species having been evaluated and probably less than 0.2% of the millions that exist are the main cause of the downfall of number of insect species under the Endangered Species Act. It is due to lack of qualified entomologist (Lugo, 2006). According to Convention on Biological Diversity (CBD), insects are a component of biodiversity and they provide essential ecosystem services. However, the Endangered Species Act (ESA) has the potential to eliminate the impact of habitat change on insect species (Lugo, 2006). In 2006, the IUCN approach to conserving insects is at the same time, three major insect groups i.e. butterflies, dragonflies and dung beetles were selected for IUCN Sampled Red List index. (Spector, 2008; Samways, 2007; Nichols *et al*., 2007). 1,255 insect species are evaluated for inclusion within the International Union for Conservation of Nature (IUCN) and Red List of Threatened Species (Nichols *et al*., 2007). Moreover, it is difficult to calibrate truth proportion of insects which may be threatened on a worldwide scale.

Conservation of insect biodiversity in 21 century

Insects are a major component of ecosystem but due main factors such as Global environmental change, land transformation and contamination causes loss of insect diversity. Insect conservationists need better decision makers, stakeholders, and land manager which illustrate the multiple strategies for saving insects at local levels. Although economics is important for funding of research strategy and implement insect conservation based on value. First we need specific strategies for insect conservation which aims to understand and promote human care for insects and also promoting human and insect's well-being (Simaika and Samways, 2018). However, according to an effective strategy conveys the message for conservation of insects which is essential for our future survival (Kritsky and Smith, 2018; Samwaysa *et al*., 2020; Spector, 2008) and the various key factors for insect conservations are

- Maintain tropical forest for insect diversity particularly in high-endemism areas.
- Military training areas, golf courses, wind turbine sites, airports, and railway embankments also provide refuge for many insect species.
- Harmful pesticides must be avoided in the conservation area.
- Instigating agro-ecological approaches improve the production of landscape away from that of conventional agriculture towards protected areas which help in conservation of insects.
- Organic farming increases up to 30% in species richness of insect.
- Landscape which considers crop field increase insect species diversity.
- Red List assessments are the starting point for conservation and contribution to raising the profile of the threats facing insects.
- The global insect assessments uses standardized methods of transect counts to assess global trends.
- Citizen scientists are involved in the data gathering, leading to an estimate of how this insect group is changing with time across the globe.
- Rapid assessment programmes have discovered many new insect species, especially in biodiversity-rich areas of the world. Insect assessment projects shedding light on the status of insect species.
- New bioinformatics and cyber taxonomy tools are helpful for delivering urgently needed information on the taxonomy, distribution, and conservation status of insect species.
- Taxon-focus databases are helpful for generating or providing taxonomic information, natural history, images and distribution data on major insect orders
- Geographically, focused databases such as Nature Serve and Info Natura along with globally federated data bases such as the Global Biodiversity Information Facility helps in monitoring of insect species.
- Mapping is valuable for assessing where species occur across a designated area and used for species predictive distribution modelling, which aids in discovery of new species in an area.
- Timing of monitoring is crucial for insects especially for rare species and might not be easily detectable.
- Environmental DNA (eDNA) is the sampling of genetic materials hed from living organisms which obtained directly from environmental samples and also determine the historic data of insect species.
- Another approach is to use higher insect taxonomic groups as a surrogate.
- An important feature of maintaining insect diversity is that specific strategies using selected,

effective surrogates and indicators. However, other interventions are required as a result of strategic monitoring.

Conclusion

Insects can be found in many places and insect biodiversity conservation generates information on the status, biology and needs of insect species. Insects are covered under many international conventions such as Convention on Biological Diversity, Biodiversity Action Plans and Agri-environment schemes. The trainings on insect research give public awareness about relation between insect with ecosystem. However, the National, International and Multilateral Institutions are finally receptive to the protection of insect biodiversity. As a result, entomologists' potential for having a positive impact and contributing to a sustainable future has never been greater. The challenge is to engage more fully with the thousands of entomological researchers and collectively bring them their vast energy and expertise in the conservation playing field at last.

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Chapter
[19]

Aquatic insect's biodiversity: Importance and their conservation

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Abstract

Insects are important representatives of the biodiversity of ecosystems. A majority of the insect species lives in freshwater environments, such as swamps, ponds, lakes, springs, streams and rivers these are called aquatic insects. There are about 8600 species of insects, falling under 12 orders, 150 families, known to inhabit diverse freshwater ecosystems. They play important ecological roles in keeping freshwater ecosystems functioning properly. There are many different kinds of aquatic insects as almost every type of freshwater environment habitat from puddles to river to lakes, including both lentic and lotic habitats, can belong to various species of aquatic insects. Aquatic insects are considered as model organisms in analyzing the structure and function of the freshwater ecosystem because of their high abundance, high birth rate with short generation time, large biomass and rapid colonization of freshwater habitat. The aquatic biodiversity gets affected by several factors such as industrial pollution or anthropogenic activities. Hence, this chapter is discussing about the diversity, habitats, roles, constraints and conservation of aquatic insects.

Keywords Aquatic, Biodiversity, Conservation, Ecological indicator, Insects

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Introduction

India is one of the mega diverse countries, with a notable diversity of aquatic habitats of about 3,166,414 Km² with significant variations in rainfall, altitude topography and latitude. Insects are the most diverse group of organisms in freshwater. Estimates on the global number of aquatic insect species derived from the fauna of North America, Australia and Europe is about 45,000, of this about 5,000 species are estimated to inhabit inland wetlands of India (Amaravathi *et al.,* 2018; Rao *et al.,* 2020). Aquatic insects of inland wetlands comprise some well-known groups like mayflies (Ephemeroptera), dragonflies (Odonata) and caddiesflies (Trichoptera). Aquatic insects such as dragonflies and damselflies (Odonata) are very colourful and prominent insects of the wetlands. Different functional feeding groups of aquatic insects such as shredders, scrapers, filter feeders and predators are important links in nutrient recycling (Subramanian and Sivaramakrishnan, 2007; Collins, 2012). Aquatic insects primarily process wood and leaf litter reaching the wetland from the surrounding landscape. Nutrients processed by aquatic insects are further degraded into absorbable form by fungal and bacterial action. Plants in the riparian zone absorb this nutrient soup transported through the wetlands. In addition to this significant ecosystem function, aquatic insects are also a primary source of food for fishes and amphibians.

Evolution of aquatic insects

The origin of aquatic insects has been controversial and doubts still exist as to whether or not insects are primarily or secondarily adapted to aquatic environments. The widely accepted view is that the ancestor of myriapod-insect group (millipedes, centipedes, and insects) lived in leaf litter areas along margins of pond like environment. Primitive insects of this moist environment were ancestors of aquatic insects (Sharma *et al*., 2020). Their fossil record extends to Devonian in the Paleozoic era. Among extend aquatic insects, dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive and only insects with aquatic juveniles. The understanding of aquatic insect evolution and phylogeny has been hampered by poor fossil record of freshwater animals. Living aquatic insects represent 12 insect orders (Figure 1). Of this, larvae of species of mayflies (Ephemeroptera), dragonflies and damselflies (Odonata), stoneflies (Plecoptera), alderflies (Megaloptera), lacewings (Neuroptera), flies (Diptera), caddiesflies (Trichoptera), moths (Lepidoptera) and wasps (Hymenoptera) are aquatic with terrestrial adults Larval or nymphal and adult stages of aquatic beetles (Coleoptera) and bugs (Hemiptera) are fully aquatic (Subramanian and Sivaramakrishnan, 2007).

Aquatic insects' orders

Colembola: A small group of six legged arthropods that have a specialized tail that allows them to spring from place to place. Common around vegetation and quiet edge waters. Usually found on o near

Figure 1. Important aquatic insect orders in aquatic ecosystem.

the water's surface.

Ephemeroptera: Mayflies are some of the best-known aquatic insects. Massive hatches are common near Lake Erie that require shovels to remove the dead carcasses from the streets. Mayflies live in both lentic (lakes) and lotic (rivers) systems, however because of their breathing mechanisms heavily silted and polluted streams and lakes are usually void of mayflies.

Odonata: Dragonflies and Damselflies are some of the most distinct aquatic insects. They are usually associated with vegetation and are commonly found in wetlands and backwaters of streams and lakes. They are predators of other insects and even small fishes. They are easily identified by a special mouth-part that protrudes out from their body to capture prey from a distance. The adults are beneficial because they feed on large amounts of mosquitoes.

Plecoptera: Stoneflies are found primarily in streams. They require a larger supply of oxygen to survive than other aquatic insects. Stoneflies can often be seen doing "pushups" after capture by humans in order to stimulate water movement along their bodies to increase oxygen flow. These insects are nearly absent from degraded and polluted streams.

Hemiptera: Many people may know these as water striders, commonly seen on the water surface skating quickly around. These insects are highly predacious on other insects and can put quit a toll on some species such as the larval stage of mosquitoes and other diptera. Water striders are not the only species in this order, others include the back swimmers and giant water bugs. Giant water bugs are also known as fish killers because they have been known to attack small fish and even ducklings. Others might know them as toe biters or stabbers because of what they might do to an unsuspecting bare foot while creeking.

Megaloptera: Smallmouth fisherman may be familiar with this order which includes hellgrammites, a ferocious looking insect that can reach 3 or more inches with giant pincher mouthparts. These are common in riffles of streams and rivers. Other alderflies are common to backwaters and areas with heavy organic matter in the water.

Neuroptera: Closely related to the megaloptera, this order is mainly terrestrial, however, there is a small group of aquatic species that are found only in conjunction with freshwater sponges of which these small insects feed upon. This is a very minor order.

Trichoptera: Caddisflies are an interesting order of insects because they build casing to hide in. They place these under and on rocks using a sticky webbing to keep tem together, some even use webs to capture food. These casings are specific to each family and many can be identified by just the casing because of the shape or type of material used in construction.

Lepidoptera: Most butterfly and moth larvae are terrestrial; however, there are a few that have an aquatic larval stage. These caterpillars are closely related to vegetation in the water, from which they feed upon. Some aquatic caterpillars are harmful to rice patties and water lilies, however some may have potential to be biological controls for invasive or pest aquatic plants.

Coleoptera: Beetles are one of the most diverse order of aquatic insects. Some only have larval stages in the water, while others also live in the water as adults. Some may know one family as whirligig beetles, the little round bugs one sees spinning around in circles on the surface of the water. There are also water pennies that are found stuck to rocks that resemble a small flat circle crawling around amongst the algae. Beetles can be found in all aquatic habitats.

Hymenoptera: Hymenoptera includes terrestrial species such as ants, bees and wasps. There are a few wasps, however, that are parasitic to aquatic species and therefore dive underwater to lay their eggs. Some families lay their eggs in midges or water pennies, others lay their eggs in fishing spiders. As the larvae develop, they eat the parasitized individual fornourishment.

Diptera: The true flies are found in every aquatic habitat imaginable from water left in an abandoned tire to the most pristine mountain stream, from the depths of a lake to the riffles of a stream, brackish to fresh water they all contain fly larvae. The best-known fly larvae would be that of mosquitoes, however, one of the most important larvae ecologically are that of midges. Many may feed these to their fish known as blood worms. Blood worms are the favorite food of yellow perch, trout, darters and many other fish species (Voshell, 2002).

Morphological and physiological adaptations

Aquatic insects have tackled the problem of living in aquatic environment by evolving various morphological and physiological modifications.

Air-tubes: To obtain atmospheric oxygen, cutaneous and gill respiration, the extraction of air from plants, hemoglobin pigments, air bubbles and plastrons. Air-tubes are present in aquatic bu (Hemiptera) and files (Diptera) restricting their activity to water surface (Subramanian and Sivaramakrishnan, 2007).

Cutaneous and gill respiration: It is widespread in the immature stages of most of the aquatic insects. This helps them to live among submerged substrates. Adult beetles and bugs often respire by the use of an air bubble. Some species use plastron (a system of microhairs or papillae) that hold an air film (Buck, 1962; Subramanian and Sivaramakrishnan, 2007).

Plastron respiration: Helps these insects to stay longer under water. Chironomid (Diptera) larvae living in eutrophic aquatic habitats survive in low oxygen levels through the use of haemoglobin pigments. One of the major physical forces faced by aquatic insects of running waters is water current (Thorpe, 1950).

Aquatic insect morphology: In running waters, aquatic insect morphology is closely related to hydraulic stress and the necessity to remain in close contact with the substrate. A diverse range of body modifications are present in aquatic insects. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects. Morphological adaptations are closely followed by behaviour adaptations. Aquatic insects avoid water current by burrowing into the substrate or occupying a space in the substrate with minimum hydraulic stress such as rock crevices or under the rock (Havel and Shurin , 2004)

Life cycle adaptations: Aquatic insects have evolved diverse life history strategies to suit their environment. Many temporary pool breeding species have egg stage which can remain in total dry condition (eg: *Aedes)*. In many species of caddies flies a gelatinous egg mass matrix protect the eggs and larvae from desiccation and freezing for months together. Some species have staggered hatching which prevents overcrowding of newly hatched larvae. Very few aquatic insects have adapted to a completely submerged life cycle (Pritchard *et al*., 1996). Most of the aquatic insects spend atleast one part of their life cycle in terrestrial habitat. A major problem in being completely submerged is respiration. Many species have developed morphological and physiological adaptations to survive in particular oxygen concentration. The distinction is being very evident in running and standing water, where the former is very well oxygenated than the latter. This is one important factor that determines the distribution of groups like mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddiesflies (Trichoptera). These groups depend upon dissolved oxygen and achieve their maximum diversity in running water. Among holometabolous aquatic insects, aquatic pupa is found in caddiesflies (Trichoptera), flies (Diptera) and aquatic moths (Lepidoptera). Aquatic beetles, alderflies (Megaloptera) and lacewings (Neuroptera) have semi aquatic or terrestrial pupa (Lancaster and Downes, 2013). During the course of life, aquatic insects encounter diverse physical environmental conditions, the most pronounced being temperature. The temperature varies daily and seasonally. This variation in temperature affects emergence pattern of aquatic insects. In tropics because of relatively constant temperature, many pool breeding species show continuous emergence throughout the year. However, in the Western Ghats, most of the stream breeding species emerge during pre- and post-monsoon months. Some species in tropics follow an emergence pattern coinciding with phases of moon.

- Slow season life cycle - Mayflies, Stoneflies, And Caddis flies
- Fast season life cycle - Caddis flies and dragonflies
- Non seasonal life cycle - Hellgrammites

The presence of diapausing egg and pupa are important life history evolutions that help insects to survive unfavorable conditions (Merritt and Wallace, 2001). Aquatic insects complete single or multiple generations during a year. Some tropical species have life cycle greater than a year. Life cycle completion time for a species varies with altitude and latitude.

Feeding strategies: Essentially all aquatic insects are omnivorous, at least in their early instars. Species which use similar morpho-behavioral mechanisms for food acquisition have evolved similar mouth parts. This has facilitated classification of aquatic insects to functional feeding groups, which is equivalent of guild. The "functional group" approach reflects both convergent and parallel evolution leading to functionally similar organisms. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional groups are shredders, collectors, scrappers, predators and piercers (Ramírez and Gutiérrez-Fonseca, 2014).

Scrapers: Scrapers have special mouthparts that remove algae growing on the surface of rocks or other solid objects. These mouthparts work like a sharp blade to remove the outermost layer of algae, which is attached very tightly but is very nutritious for those insects equipped to remove it.

Collectors: Collectors acquire small pieces of decaying plant material (detritus). Some kinds use long hairs on their head or legs or silk nets to filter these small particles out of the water. Other kinds of collectors use their mouthparts to gather fine particles lying on the bottom and shove this material into their mouths.

Shredders: Shredders have mouthparts that are designed to nibble of pieces of soft vegetation, such as leaves, flowers, or twigs, and grind up this material. Most aquatic insects shred pieces of vegetation that have dropped of plants and are decaying. Most of this material comes from trees and shrubs that grow on land at the edge of the water. Only a few kinds of aquatic insects feed on parts of live plants that grow under the water.

Predators: Predators feed on other animals that are alive. Predators often have special structures for catching and subduing their prey, such as strong jaws with teeth, a sharp beak, or spiny legs. Predators eat other invertebrates most of the time, but some are large and strong enough to catch small vertebrates, such as fish and tadpoles (Mary *et al*., 2015).

Aquatic insects and their habitats

Aquatic insects are adapted to either running waters (streams and rivers) or standing waters (ponds and lakes). These habitats can also be viewed as erosional habitats frequently colonize lake shorelines. Similarly, many species of depositional habitats are common in flood plain pools and backwaters. The habitats for the aquatic insects can be visualized within the framework of various spatial -temporal scales. At a spatial scale, it ranges in size from particles of few millimeters to the entire drainage basin, which extends to squares of kilometers. Temporally, the changes in the habitats can be visualized from days to thousands of years. The permanence of the physical structures of the habitats varies with the spatial scale. This ranges from few days for individual grain and microhabitat to thousands of years for the drainage network. Insect communities of the wetlands respond to this spatial temporal variation as well. Within a given habitat, aquatic insects maintain their location by clinging, swimming, skating or burrowing into the habitat (Hershey *et al*., 2010).

Distribution of aquatic insects within a habitat is determined by intricate interplay between substrate, flow, turbulence and food availability. The habit (mode of locomotion, attachment or concealment) of a given species determines the frequency of movement within the habitat Substrate, an important physical component of habitat is very complex. The water current and the nature of the available parental material determine the physical nature of the substrate. The organic detritus adds complexity to the substrata and can strongly influence the organism's response to the substrate. It has been established across continents and biomes that the faunal composition changes with the substrate. Sand is a relatively poor habitat with low (streams and rivers) or depositional (ponds and lakes). Both stream/ river currents and lake shoreline waves create erosional habitats while lake basins, river flood plain pools and stream/river backwaters provide depositional conditions. Species adapted to erosional abundance and diversity (Subramanian and Sivaramakrishnan, 2007). Relatively, the diversity is high in silty sand and biomass may be high and diversity low in muddy substrata. The presence of sand and silt reduces and changes fauna. At least in stony substrata it is known that the space available for colonization determines species abundance. In general, diversity and abundance increase with substrate stability and the presence of organic detritus (Collins, 2012).

Societal benefits of aquatic insects

A high diversity of aquatic insect species is of value to humans and animals for a variety of reasons, out of which four are particularly important. They are the role of these insects in food webs, biomonitoring, fishing, and controlling noxious weeds (Nair *et al.,* 2015).

Food webs: A high abundance (or density) of aquatic insects helps assure the processing of large amounts of nutrients. A high diversity (or taxa richness) of aquatic insects helps assure diversity of resources and ecosystem services (e.g., nutrients, habitats) and effective use of all available resources in both space and time.

Aquatic insects in biomonitoring: Biological monitoring or biomonitoring is the systematic use of living organism or their responses to determine the health of aquatic ecosystem. Fish, algae, protozoans, and other groups of organisms is being used in water quality assessment but macro invertebrates which largely consist of insects are more frequently used. They are suitable and sensitive indicators of water quality and ecosystem health because: (1) they are ubiquitous and, consequently affected by perturbations in many different aquatic habitats; (2) the large number of species respond to a range of environmental stress; (3) their sedentary nature relative to other aquatic organisms permits effective determination of spatial extend of perturbation; and (4) long life cycles allow to examine temporal changes in abundance and age structure (Bonada *et al*., 2006).

Aquatic insects allow us to know about the health of a stream, pond, river or a lake. Aquatic insects are good indicators of water quality because they are affected by the physical, chemical, and biological conditions of the water body. They cannot escape pollution and show the collective effects of short- and long-term pollution events. They are particularly sensitive to the water quality like the amount of dissolved oxygen. Aquatic ecosystems are under increasing pressure from various kinds of disturbances (Tachet *et al.,* 2003).

Mayflies are considered as "keystone" species and their presence is believed to be an important indicator of oligotrophic to mesotrophic (low to moderately productive) condition in running waters. Presence of saprophilic species of diptera indicates that water bodies are grossly polluted with poor water quality characterized by low oxygen and high nutrient concentration (eutrophic). Large numbers of pollution tolerant chronomids are often indicative of poor water quality (characterized by low dissolved oxygen and high nutrient concentrations). Excellent water quality conditions are often characterized by relatively low densities and high species diversity. The high abundance of *Chironomu*s sp. in aquatic body indicates eutrophic nature of water body. These bugs, since they can survive in heavily polluted areas, are often used to gauge the toxins in an environment (Papacek, 2001; Wollmann, 2001). The members of family Gyrinidae (whirling beetles) are found in fresh water ponds, lakes, open flowing streams etc. The members of Haliplidae (crawling water beetles) live among aquatic vegetation along the edges of ponds, lakes, streams and creeks.

Fishing of aquatic insects: Aquatic insect biodiversity is of considerable interest to society because these animals are so important in the diets of many fish species, including species that are commonly consumed by humans for food. People who fish with natural or artificial baits have long had particular interest in them. Anglers for centuries have attempted to imitate the form and colour of various aquatic insects on hooks (or angles) in the hope of tricking fish to swallow them and become snagged. Mayflies, caddisflies, stoneflies and non-biting midges have been grouping whose species are most commonly imitated. Larvae, pupae and adults are imitated and presented to the fish in ways intended to replicate the behaviour of those forms as they grow on the bottom substrate, drift in the current, emerge from the water surface, or return to the water as egg-laying females or dying adults. A high diversity of these insects in a particular stream, each with its own specific emergence time, assures that food is available to the fish through much of the year and through different times of day.

Control of noxious weeds: Several species of noxious, invasive weeds have become problems in parts of the world where they out-compete native species, clog otherwise navigable waters and water-intake structures, and exclude food-fish species. Herbicides often are employed to control these weeds, but some success also has resulted from the introduction of insect herbivores. For example, in the USA, alligator weed (*Alternanthera philoxeroides*), an invasive species from South America, has been controlled successfully by three important herbivores: alligator weed stem borer, alligator weed flea beetle and alligator weed thrip. Another example is the successful control of commo water hyacinth (*Eichhornia crassipes*) an invasive species from Brazil, by two imported species of weevils (Coleoptera: Curculionidae) and one species of imported moth. Studies can be attempted to discover species of aquatic insects that may help reduce or eliminate weeds.

Forensic Entomology: The importance of aquatic insects in terms of Forensic Investigation can be very much useful in Drowning cases like death due to submersion which is substantial which is most probably accidental. Aquatic insects like Anax Parthenope, Lestes Sponsa, Scarlet Skimmer, etc. are a few which are very much useful in a death investigation. The investigation of submerged bodies in context with aquatic insects usually requires a coordinated effort and the expertise of multiple agencies especially dealing with natural water bodies. Insects mostly involved in the forensic investigations are true flies or Diptera. The predominant species in this order are Calliphoridae (blow flies), Sacrophagidae (flesh flies) and Muscidae (house flies). Calliphoridae (blow flies), Sacrophagidae (flesh flies) may arrive within minutes following death. Muscidae (house flies) delay colonization until the body reaches bloat stages of decomposition (Joseph *et al*. 2011).

Environmental threats to aquatic insects

Aquatic insects are also vulnerable to a wide range of human-induced factors. Because they live for several years under water, many of these insects are extremely sensitive to water quality. In fact, the assemblage of species present can serve as an indicator of the stream's health, and scientists can monitor stream quality using what is called a biodiversity index. For example, stoneflies are known to have low tolerance to poor water quality, so the presence of stoneflies indicates a healthy stream. If the stream only contains worm-like animals and fly larvae, however, it may be experiencing pollution problems, as these animals have high tolerance to poor water quality. Some factors that can reduce water quality include trash dumping near streams, runoff from areas with improper drainage, city storm drains where people dump a variety of liquids, and changing habitat around the stream.

Pesticides (water pollution): Agricultural areas can be especially problematic, as fertilizers and pesticides may leach into the stream, and rain may wash an excess of sediments into the stream. As these sediments cover the streambed and darken the water, they make it difficult for insects to breath, hunt, and access shelter. Furthermore, changing the habitat around the stream can alter the stream's ecosystem. When a forest is cleared and leaf litter ceases to enter the system, there may be less decaying organic matter in the stream, changing the natural flow of the food chain.

Industrial pollution: In recent years, freshwater ecosystem has experienced serious threats from human activities such as industrial effluents, agricultural activities, urban waste management issues, and increase in urbanization (Meijide *et al*., 2018; Zhu *et al*., 2018). In addition, climate change impacts resulting changes in abiotic factors such as precipitation and temperature levels have affected the normal function of aquatic ecosystems including reproduction and feeding. These pollution levels have also affected the habitats of aquatic flora and fauna (Schmeller *et al*., 2018). Relationship between some aquatic insect species (Ephemeroptera, Plecoptera,Trichoptera and Odonata) and some heavy metals (cadmium, lead, copper, zinc, nickel, iron and manganese) and boron studied by Girgin *et al*. (2010) and reported that if contamination was high due to this heavy metals there may be absence of this insect orders in aquatic condition (Figure 2).

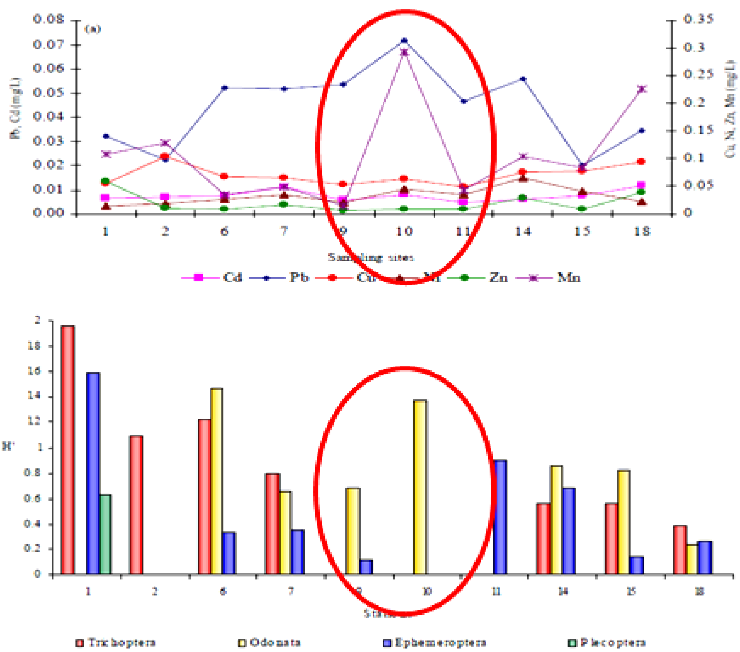

Figure 2. Relationship between heavy metals and aquatic insects (Girgin *et al*., 2010).

Climate change as a potential threat: Changes in climate occur as a result of internal variability of the climate system and external factors (both natural factors such as solar radiation, cloud formation, and rainfall and those resulting from human activities, including increased concentrations of greenhouse gases) in the atmosphere (Figure 3). Impacts of human activities also extend to other aspects of climate, including ocean warming and sea level rise, continental average temperatures, temperature extremes and wind patterns (IPCC, 2007) Aquatic systems are influenced by the changing climatic conditions which in turn determine the ecological distributions of organisms (Vannote and Sweeney, 1980; Li *et al*., 2013). The effects of climate variations on species diversity depend on the nature of variation, whether it is predictable or unpredictable. The latter could have more complicated effects on species richness and the systems. The degree and extent of the ecological consequences of climate change in freshwater ecosystems depend largely on the rate and degree of change in three primary environmental drivers: the timing, degree and duration of the runoff regime; temperature; and alterations in water chemistry such as nutrient levels and particulate organic matter loadings (Rouse *et al*., 1997; Vincent and Hobbie, 2000; Poff *et al*., 2002). Aquatic insects are affected by alternations in temperature and hydrological regime during their entire life cycle (Chen *et al*., 2011; Sandin *et al*., 2014). Plecoptera as nymphs generally prefer cool and clear streams with high dissolved oxygen content and substrates that vary from leaf litter, cobbles, and rocks. However, the specific microhabitat depends on a variety of environmental factors such as the nature of the substratum, current regime, presence of other organisms, and local variations in water chemistry and temperature (Jonsson *et al*., 2013). Refugial habitats characteristic of thermal stability with low-nutrient and oxygen rich waters are under threat owing to the effect of the undue raise in global mean temperature (Fonnesu *et al*., 2005). Though most of the freshwater organisms are adapted with specific traits to survive the conditions caused by naturally occurring mild to moderate climate variations, it is not always possible for certain sensitive species.

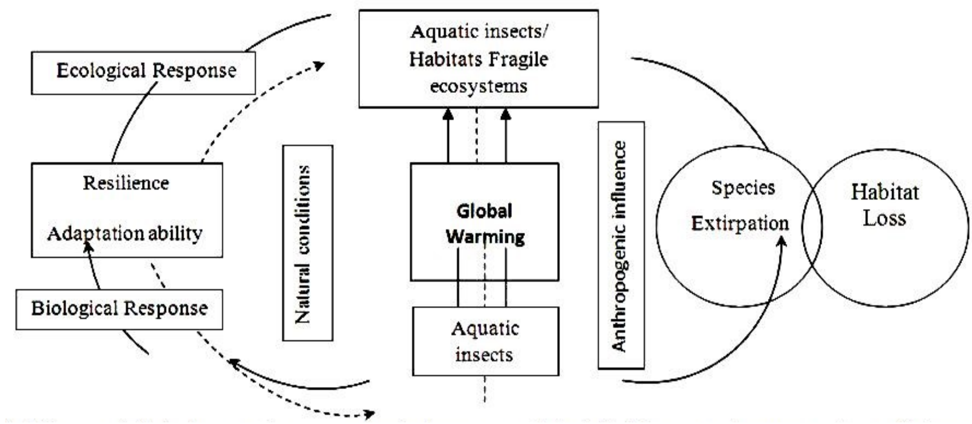

Figure 3. Effects of global warming on aquatic insects (Sundar and Muralidharan, 2017).

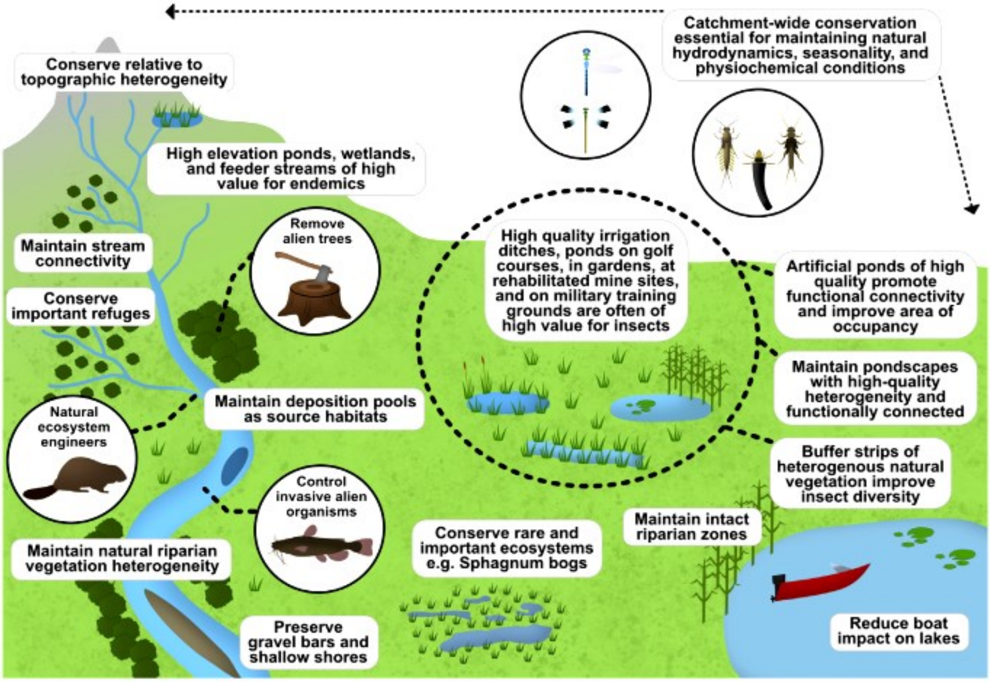

Figure 4. Essential components for aquatic insect conservation (Samways *et al*., 2020).

Dispersal ability and rate are essential traits in adapting to environmental changes, aquatic insects are said to have dispersal rates that may be sufficient to keep up with climate change (Havel and Shurin, 2004). However, the dispersal rates of many other freshwater invertebrates across drainages appear to be very slow (Strayer, 2006) almost surely too slow to keep up with the pace of climate change that current models predict.

Approaches of aquatic insects conservation

Catchment-wide conservation of freshwater systems is an important management objective. At the local level, conservation of headwater streams is particularly important, as are high-elevation ponds for endemic insects. Maintenance of historic river dynamics is essential, including historic seasonality and physiochemical water conditions (Figure 4). Also important are location-specific factors such as consideration of river network connectivity, sensitive land use, topographic heterogeneity, and biotic interactions, as well as promotion of macrophyte and riparian/bank vegetation quality and diversity for adult aquatic insects as well as protecting the areas of open water. Channelization should be avoided as it greatly reduces insect diversity and causes local hydrological drought. On the positive side, artificial, shallow and well vegetated shorelines should be created, while also maintaining substrata that are rich in organic matter, both of which increase insect diversity. Historic vertebrate engineers, especially beavers, should be recovered. Although alien trees sometimes can be a substitute for loss of indigenous trees, in general alien trees must be removed, leading to considerable insect habitat improvement. Maintenance of floodplains and ensuring gravel bars are intact has become crucial for many terrestrial as well as aquatic insects, as is maintaining or restoring intact hydrology, and careful management of saline systems (Samways *et al*., 2020).

Connectivity is important for freshwater systems as it is for other systems, most importantly for many ponds making up a pondscape network. Pondscapes should be of high quality, with high pond heterogeneity, connectivity and size variation, as well as high functional connectivity among each other and to deposition pools of streams and rivers. It is important to maintain natural dynamics of freshwater systems in general for improved vegetation and insect heterogeneity. However, as some aquatic insect species are adapted to short hydroperiods, it is necessary to retain a variety of both permanent and ephemeral ponds and deposition pools of streams as part of pondscape heterogeneity. In turn, for some aquatic insects, permanent ponds and pools can be source habitats from which to colonize ephemeral ponds. Buffer strips instigated around ponds mitigate the effects of agriculture.

In turn, well-designed artificial ponds can provide valuable supplementary habitat, as can high-quality irrigation ditches for marshland insects, and storm water ponds for aquatic insects. Increased natural vegetation heterogeneity benefits both agricultural and urban ponds, with city ponds having the added benefit of increasing insect conservation awareness. In turn, there is great opportunity for improving artificial ponds, and doing so greatly improves pond functional connectivity across the landscape (i.e. improves the pondscape). Certain human-designed landscapes provide a great opportunity for aquatic insect conservation, including garden ponds, roughs of golf courses, and military training areas. There are also some special cases significant for aquatic insect conservation. These include reducing ship and boat wave impact, introducing biological control of invasive water plants, preservation of river-lake ecotones, rehabilitation of mining pools, retention of well managed Sphagnum bogs, removal of alien predators such as fish, erection of physical diversion structures to deflect certain threatened flying adults, and in some special habitats reducing tourist impact through use of designated paths and duckboards (Sivaramakrishnan *et al*., 2014; Samways *et al*., 2020).

Conclusion

Conservation of natural resources and biodiversity has become urgent issues in recent years for attaining an environmentally sustainable future. While a lack of data has historically excluded the use of many taxa as possible indicator. Growing number of studies on the habitats and distributional pattern of certain aquatic insects is making their use increasingly suitable. Aquatic insects are used for monitoring the health of aquatic environments because of their differential responses to stimuli in their aquatic habitat and determining the quality of that environment. The improvement and development of existing and new biomonitoring tools using aquatic insects are a major effort among aquatic entomologists.

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Chapter
[20]

Insect biodiversity and their conservation for sustainable ecosystem functioning

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Abstract

Insects are the most species-rich group on the Earth, hence it play numerous crucial roles in ecosystem functioning and the global-economy. The conservation of insect diversity is therefore a topic of global importance. Threats to insect bio-diversity are rapidly increasing day by day. Six interrelated principles are emerging from recent research on the possible thanks to manage the landscape for insect and other bio-diversity conservation. A perfect management strategy is to keep up reserves and promote habitat heterogeneity while softening the disturbed matrix immediately surrounding the reserve. Outside reserves, put aside land for biodiversity and simulate natural conditions and disturbance. Link good-quality habitats with corridors, which has both short-term ecological value and long-term evolutionary value and may be a buffer within the face of worldwide global climate change. Permeating these six landscape principles may be a population-level approach, involving the meta-population trio, which are large habitat size, good patch quality, and reduced patch isolation. Overlying these coarse-filter, landscape principles is that the fine-filter, species approach, which recognizes the requirements of particular species under threat.

Keywords Insects, Conservation, Diversity, Management strategies, Threats

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Introduction

Biodiversity is that the basis for human survival. The composition and richness of species assemblages also strongly influences ecosystem functioning and stability (Naeem *et al*., 1994; Tilman and Downing, 1994; McCann, 2000). However, following the commercial revolution, the rapid expanding human population and its economic activities have caused a dramatic loss in global biodiversity, leading to significant disturbance to ecosystems and our living conditions. Accordingly, the conservation of biodiversity has become one in every of the foremost important challenges on our planet.

***Biodiversity**:* "Variety of organisms in any respect levels, from genetic variants belong to the identical species through arrays of species to arrays of genera, families, and still higher taxonomic levels; includes the range of ecosystems, which has communities of organisms within particular habitats and therefore the physical conditions under which they live".

Evolution of insects: Biodiversity isn't static; it's a system in constant evolution from a species, in addition as from a personal organism point of view. The typical half-life of a species is estimated at between one and 4 million years, and 99% of the species that have ever lived on earth are today extinct. Biodiversity isn't distributed evenly on earth; it's evident from fossilized specimens that insects were living 400 million years ago. Evolution of insects in our universe is classed as Silurian, Carboniferous, late carboniferous or early Permian, Paleozoic and Cretaceous periods (Gullan and Cranston, 2014).

Insect diversity: Biologists have long realized the good diversity of insects. But the described insects are unknown fraction of total, no central organized database for the life on earth and also unclear what number described species exist (ZSI, 2012). Approximately 30 million species are found worldwide, of which about 1.4 million are briefly described. (Balakrishnan *et al*., 2014). The kingdom Animalia is represented by 15, 52,319 species that are described thus far globally in 40 phyla in a very new evolutionary classification. The phylum Arthropoda alone includes 12, 42,040 species, constituting about 80% of the full number of species (ZSI, 2012). Insects comprise over 75 you look after all described animal species and exhibit not only a fashionable form of form, color, and shape, but also a variety of ecological adaptations unexcelled by the other group (Springer, 2009). The most successful insect order, Coleoptera, represents about 38% (3, 87,100 species) of the insect species of the planet (Zhang, 2011).

Insects are the largest and most diverse group of organisms on earth. The total number of recorded species stands for about 1 million in number. However, there is some speculations within the scientists that the actual number of insect species may even exceed 20 million. These amazing creatures' makeup about 75% of all described animal species. Irrespective of their abundance yet they are undermined because of their size. Insects are found almost everywhere on the earth surface. They can sustain even in most inhabitable places, it may be deserts or icecaps, land or water, trenches or mountains anywhere we go we can still find the presence of an insect even in most rugged condition. All thanks to their physiological and morphological characters which helps them to adapt themselves in any condition. The general characters of an insects include three segmented body, three pair of legs, small size, short life cycle, protective exoskeleton, presence of functional wings, compound eyes, decentralized nervous

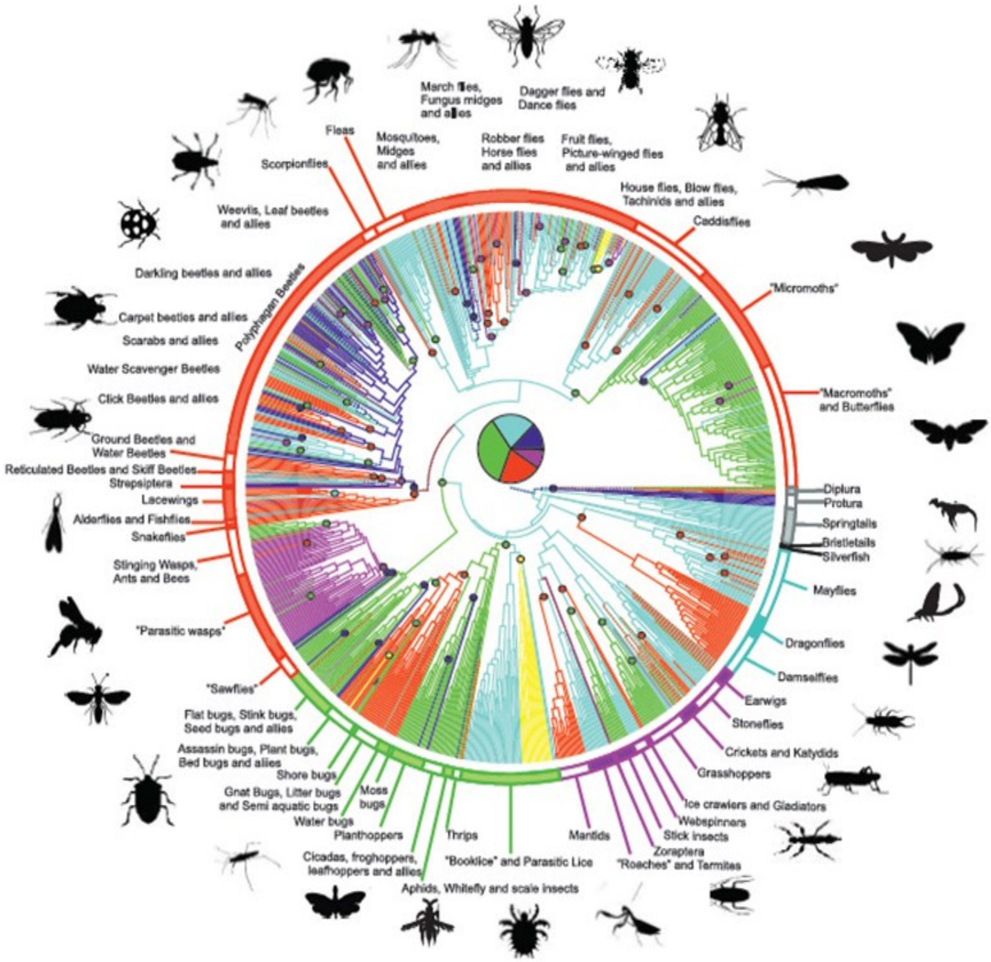

Figure 1. Hexapoda: insect diversity (Bertone *et al*., 2016)

system, open circulatory system, presence of sensory antenna, direct respiration, scattered sense organs, entero-nephric excretion, high fecundity, food specificity, various morphological physiological and behavioural adaptations, etc. These are some of the factors that are responsible for insect abundance and also their humongous diversity. The magnificence of insect species diversity is greatest in tropical region, specifically in neo-tropics (Figure 1).

The diversity of insects today as far as we know is the richest it has ever been. Variety is so great that the insects make up three-quarters of all species. Insects have radiated into so many diverse forms that we have not been able to describe a large chunk of their population. They are a major part of this huge ecological machinery we observe around us. Insects are one of the earliest life forms that continued to radiate through the process of variation and selection, to flourish the earth with a fantastically rich

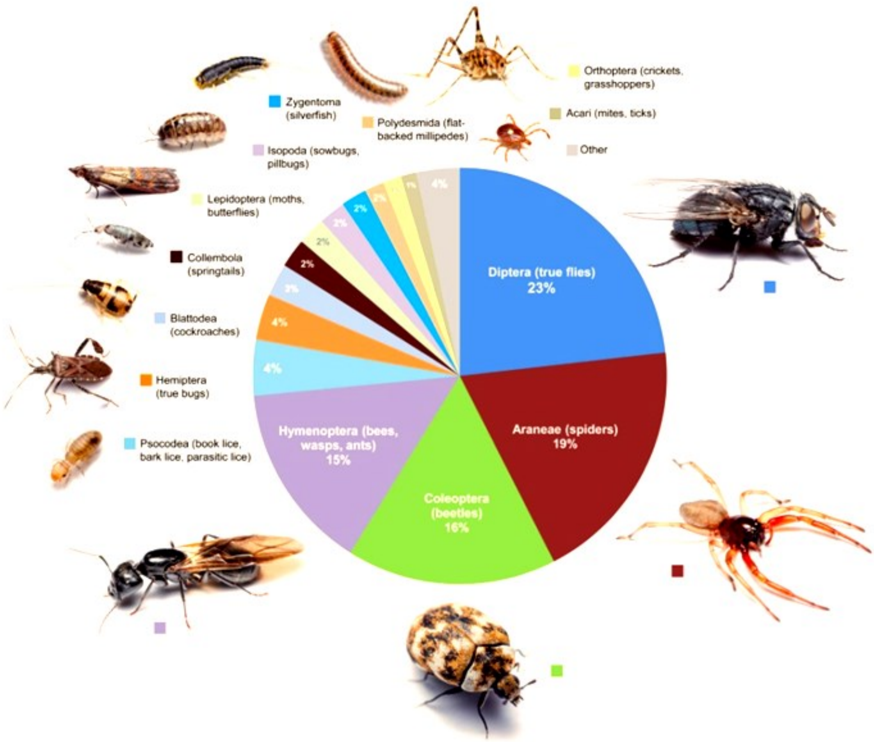

Figure 2. Dominant wise diversity of insect orders (Bertone *et al*., 2016)

assortment of life forms which is quite mesmerizing to scrutinize. Humans are a latter-day arrival who hold in their palms the future of the insect mosaic. This fascinating insect variety is losing its special and compositional integrity as we enter the new era, the homogenocene, which is a mere blink of a geological eyelid (Figure 2).

Taxonomic classification of insects: Presently, 63,760 species of insect (Hexapoda) in 658 families representing 27 orders and three class are reported from India. Of these, eight orders, viz. Coleoptera, Lepidoptera, Orthoptera, Diptera, Hemiptera, Odonata, Hymenoptera and Thysanoptera, constitute the bulk 94 per cent of the insect fauna. The remaining 21 orders are represented by small numbers 6 per cent of species (ZSI, 2012).

Forest insect biodiversity: About 67,000 species of insects are recorded from various ecosystems in India. Of these, 16,000 species are specifically recorded from the forests (Beeson, 1941; Nair and Mathew, 1993). However, this estimate might not hold true considering the actual fact that a lot of species found in other ecosystems also occur within the forests. The forests of India range from the snow-clad boreal forests of Himalayas to the wet evergreen forests of the Western Ghats. Many parts of those forests are still not explored.

Aquatic insect biodiversity

Freshwater lakes are integral a part of urban ecosystem and supply numerous benefits to groups of people directly or indirectly. Aquatic insects are extremely important in ecological systems for several reasons and are the first bio-indicators of freshwater bodies like lakes, ponds, wetland, and rivers. The presence or absence of certain families of aquatic insects can indicate whether a specific water body is healthy or polluted (Majumder *et al.*, 2013) but 3% of all species of insects have aquatic stages in some freshwater biotopes.Aquatic insects are used for monitoring the health of aquatic environments because of their differential responses to stimuli in their aquatic habitat and determining the quality of that environment (Merritt *et al.*, 2008).There are so many different kinds of aquatic insects, but the major groups includes, mayflies, stoneflies, true bugs, dobsonflies, water beetles, tricopterans, true flies,dragonflies and damsenflies (Voshell, 2002).

Biodiversity of bioluminescence insects: Bioluminescence or living light could be a remarkable phenomenon within the organisms living on this earth, were the energy is release by a reaction within the sort of light emission. There are not any luminous flowering plants, birds, reptiles, amphibians or mammals in nature. Though bioluminescence is generated by various organisms, it's highly developed in insects. The samples of true or self-luminescence are found in Collembola, Diptera, Coleoptera and Homoptera. The Coleoptera constitutes the biggest bioluminescent group during which several hundred species are known to contain highly developed photogenic organs. the simplest understood luminous insects belong to the families Lampyridae, Elateridae and Phengodidae. In some lampyridae species female are wingless and sedentary, light production is therefore important for attracting the winged male (Babu and Kannan, 2002). This biological phenomenon has been exploited in space and medical research, insect pest management, and is additionally a useful tool in biotechnology.

Insect fauna of states and union territories of India*:* India's insect fauna is distributed over a good range of ecosystems, climatic regions and altitudes. The insect distribution is principally influenced by the ecological, climatic and edaphic factors, like the vegetation, rainfall and temperature. The insect fauna within the Himalayan Zone, including the mountains in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, north-west Bengal, Meghalaya and Arunachal Pradesh, is influenced by the Palearctic elements. However, the insect fauna of the desert areas of Rajasthan, Gujarat and Ladakh (cold desert) varies because of variation in warm temperature in these states. The tropical humid forests of the Western Ghats and also the eastern Himalaya are different from the island ecosystems of the Andaman and Nicobar Islands, but the best numbers of endemic species occur in these ecosystems (ZSI, 2012).The tropical evergreen forests of the eastern Himalaya and also the hills of north-east India including the states of Sikkim, Meghalaya, Arunachal Pradesh, Manipur, Nagaland, Tripura and Mizoram and north-west Bengal harbor the best number of insect species, followed by the states within which the Western Ghats fall, like Kerala, Tamil Nadu, Karnataka and Maharashtra. The third biodiversity-rich areas in terms of insects are the western Himalayan region and also the Andaman and Nicobar Islands (ZSI, 2012).There are still many inaccessible areas within the country that haven't been adequately explored for assessment of the insect wealth.

Why Insect diversity is important: Insects have important economic roles, supporting and providing livelihoods for various people, from the silk trade to beekeeping and also the pollination of most of our fruit and a variety of other agricultural produce. The outline of insects and their colourful body patterns have initiated prominent contributions to our art, literature and culture and offer great educational tools (Pyle *et al.,* 1981). In many regions, insects also form a vital component of the human diet. Some insects have great value in Chinese medicine. For example, the Chinese fungal drug Dong chongxiacao (*Cordyceps sinensis*), is that the plant organ of a parasitic fungus which develops inside the caterpillar of a ghost moth and features a very prominent role and really long history in traditional Chinese medicine. Another important application of insects is biological pest management. Insect predators are known to be more practical than many chemicals in controlling economically damaging insects. Thanks to their conspicuousness and susceptibility to environmental factors many insect taxa may be used as bio indicators (Kati *et al.,* 2004*). As an example, butterfly* population dynamics are suggested as indicators of species richness for pollinators overall and of the structural and floristic diversity of habitats, as indicators of temperature change and further ecological parameters, and of landscape distinctiveness (Peter and Settele, 2008). Ground beetles also are commonly used as bio-indicators for changes in environmental conditions because of their sensitivity to habitat change and since carabid studies are being highly cost efficient (Rainio and Niemela, 2003). In addition to their intellectual and quantity, insects are vital ecosystem components. Many of the key ecosystem functions that insects fulfil relate to interactions with vegetation. This includes various styles of herbivorous links, but also many mutualistic relationships like pollination, seed dispersal or predator defence in exchange for shelter (Qin and Wang, 2001). Plants provide the key habitat parameters for several insect species starting from shelter to breeding sites. Plant-insect interactions have direct effects, as an example on the storage and cycling of carbon and nutrients, moreover as strongly influencing succession and competition patterns in plant communities and organic phenomenon interactions (Weisser and Siemann, 2004).

Relationship between insect diversity and plants*:* Relationships between insect assemblages and plant communities are another key topic requiring urgent research attention. Insect diversity might be plagued by parameters associated with vegetation structure like plant height, plant size or leaf form (Axmacher *et al*., 2004). Insect species richness often increases with an increase in vegetation height, with the very best diversity recorded in full-grown forests (Poyry *et al*., 2006). This has been associated with greater resource availability in mature forest ecosystems. Nonetheless, interactions are highly complex, and better diversity has also been observed in open habitats as compared to closed forests, potentially in reaction to changes in microclimatic conditions (Axmacher *et al*., 2004 and 2009*)*

Plant species richness and community composition affect insect diversity. Despite the unimodal model often accustomed describe relationships between diversity and productivity a rise in plant diversity could monotonically improve ecosystem productivity (Hooper *et al*., 2005). Ecosystem productivity could potentially enhance diversity at higher trophic levels and likewise increase the variety of herbivorous insects, parasites and predators. a rise in plant diversity would have a stronger positive effect on species richness at higher tropical levels. However, a recent review found that lower trophic species responded more strongly to a rise in plant diversity than higher trophic levels in grassland (Scherber *et al.*, 2010). Increases in plant diversity would decrease the results of biological invasion, pathogen and hyper-parasitism (Scherber *et al.*, 2010). This pattern also means that increasing plant diversity could potentially enhance ecosystem stability (Tilman *et al.*, 2006). Predators are simpler in controlling herbivores in low habitat stability ecosystems than in highly stable ones (Southwood and Comins, 1976). As positive relationship been found between plant diversity and habitat stability (Tilman *et al*., 2006), plant diversity then would likely affects the connection between herbivorous insects and predators. Additionally, consistent with the resource concentration hypothesis by Root (1973), herbivores are more likely to search out and remain on hosts in monocultures. Reduced plant diversity therefore increases the potential damage to vegetation by pest species, while simultaneously reducing overall insect diversity. Supported by experiments, it's been predicted that herbivorous insect diversity is positively correlated with plant species diversity (Lewinsohn and Roslin, 2008). Increasing diversity in herbivores could further enhance the range of predators and parasites (Root, 1973). However, the connection between plant diversity and bug diversity isn't always positive, and a few studies investigating natural habitats have found an opposite trend.

Threats to insect biodiversity

Changes in habitats all across the country, particularly in fragile ecosystems, freshwater ecosystems and forests areas has impacted the insect diversity of India. Pollution of streams, particularly through drainage and siltation, has resulted in profound changes in aquatic insect communities. The introduction of exotic insects for the control of pests or weeds directly or indirectly affects the population of native insects. However, the major factor responsible for the loss of insect populations during the last few decades is the widespread use of organic pesticides (ZSI, 2011).

Effects of global climate change on insects: The worldwide climate has changed significantly during the 20th century, the typical global air temperature near the Earth's surface and oceans rose by 0.74℃ between 1906 and 2005 (Parry *et al.*, 2007). At a worldwide level, global climate change is predicted to be a key factor affecting future developments in biodiversity (Beck *et al.*, 2010), with wide-ranging effects on forest structure and native spatial distribution patterns (Sang and Bai, 2009). Insect species richness and species composition are known to be particularly strongly tormented by environmental factors like temperature and moisture (Axmacher *et al*., 2009). Global temperature change is accordingly predicted to alter the distribution and so also diversity patterns of insect communities. Many insect species have already observed to be spreading northwards within the hemisphere, some cashing in on warmer temperatures, e.g. the silver spotted skipper buttery (*Hesperia comma*), Roesel's bush cricket (*Metrioptera roeselii*), (Thomas *et al.*, 2001); however, most species have declined in reaction to climatic change (Warren *et al.*, 2001).

Research needed for insect conservation

Operational levels of insect conservation research: The research scope should enhance to search out new and effective ways for maintaining insect diversity, insect species, and bug populations. The interaction of environmental factors like abiotic (temperature, fire intensity, rainfall patterns and intensity, insolation, elevation, rockiness, water, pH, dissolved oxygen, also as contaminants, pollutants, pesticides) and biotic including vegetation structure and composition, pollen and seed, host availability directly and indirectly affect insect diversity, Although an insect's habitat is embedded in an ecosystem, some require quite one ecosystem to sustain them (Figure 3). With anthropogenic modification of the landscape, not only are conditions changed within their habitat, but also around it (Mathew *et al*., 1990).

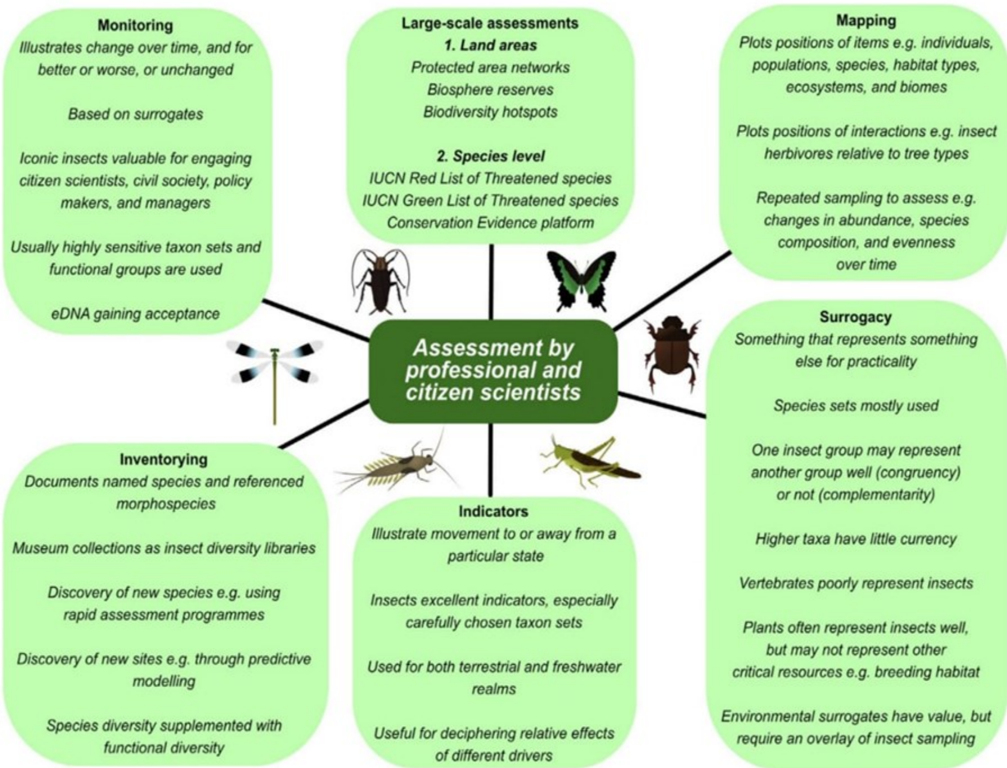

Figure 3. Essential components of assessment for insect conservation (Samways *et al*., 2020).

Species-level insect conservation: The range of genetic variation in populations and the way it's shared among individuals that determines the adaptability of a population to environmental change, whether for the higher or the more severe, and whether in response to local (landscape fragmentation, pollution) or global (climate change) impacts or both. The viability of meta-populations depends on the flow of genes that provide high value for adapting to prevailing conditions.

Insect conservation planning at the regional scale: At the regional scale, insects have a job in systematic conservation planning, which aims to spot locations and landscapes that are a priority for conservation action. the main focus is also totally on endemic hotspots, areas that are zones of ecological transition and areas that have evolutionary potential (Spector, 2002). These reserve selection procedures are : Coarse-filter (The landscape or community approach to conservation) Fine-filter (The species approach to conservation, within which the main focus is on a specific species or small number of species) and Corridor (A linear strip of land connecting one high-value conservation patch with another (also called a linkage or greenway approach) (Michael and Lindenmayer, 2018).

Surrogates in conservation planning: This shortcoming are often addressed by using surrogates of insect species diversity. Such surrogates could also be alternatives or complements, like higher taxa, species richness, rarity, endemism, threat status, and/or alternative taxa. Other kinds of surrogates include vegetation types, land systems or classes, and environmental domains. the utilization of environmental surrogates can embrace a variety of taxonomic diversity, this broad-scale approach can overlook critical small-scale habitats and special features (such as large logs sure enough saproxylic species, hills for hill topping behaviour, mud for mud-puddling, and sun-basking sites) essential to small animals like insects. the most effective to mix both environmental and species surrogates for systematic conservation planning, consensus being reached (Ripple *et al.*, 2019).

Conclusions

Although we are unable to conserve every insect population or maybe every species, civil society is now becoming responsive to the precipitous decline in insects and its severe consequences for planetary survival. As insects are braided into ecosystems, their plight is actually integrated with more expansive movements like global biodiversity conservation and global climate change mitigation. By conserving as many naturally-intact ecosystems as possible, alongside more extensive softening food- and fibre-producing landscapes, together we will get on track for leaving a sound legacy to future generations.

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Chapter
[21]

Biological control of invasive pests in India

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Abstract

Invasive species are one of the major and most rapidly growing threats to agricultural biodiversity, livelihoods, animal and human health, forestry and biodiversity which result in huge economic losses. They occur in all major taxonomic groups including viruses, fungi, higher plants, ferns, algae mosses, invertebrates, fish, reptiles, amphibians, birds and mammals. According to the International Union for Conservation of Nature and Natural Resources (IUCN) invasive insect pest is one which becomes established in natural or semi-natural ecosystems or habitat, and threatens native biological diversity. These insect pests can multiply in large numbers and cause damage to economically important crop plants. These pests become invasive in introduced area due to the absence of natural enemies and favourable environment parameters. In India, the Directorate of Plant Protection Quarantine and Storage (DPPQ&S) is responsible for implementation of Destructive Insect and Pest Act (DIPA), 1914 through Plant Quarantine (Regulation of Import into India) Order, 2003 to prevent entry, establishment and spread of exotic plant pests into India to safeguard agriculture, horticulture and forest tree plants. There are about 23 invasive insect pests reported in India. This paper reviews the various biological control options for the invasive pests.

Keywords Invasive pest, Legal restriction, Management and status, Natural enemy

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Introduction

Biological control is the reduction in population density of an organism through the use of its natural enemies. For managing invasive species, this approach has been recognized as one of most effective, cost-efficient and providing long-term control. Natural enemies (parasites, predators, herbivores, and pathogens) can reduce the host population; in turn the host abundance also influences the population levels of the natural enemies. Invasive alien species occur in all major taxonomic groups, including viruses, fungi, ferns, algae mosses, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Invasive species are hardy, long lived, voracious, aggressively pervasive, rapid growth, very resilient, generalized diet, ability to move long distances and prolific breeding. They are exotic or non-native organisms that occur outside their natural adapted habitat and dispersal potential. However, some of the invasive insect pests become invasive when they are introduced deliberately or unintentionally outside their natural habitats into new areas where they express the capability to invade, establish and outcompete native species. National Plant Protection Organizations (NPPO) has curtailed the intentional accidental or introduction of plant pests into newer areas through legal mechanisms. In India, the Directorate of Plant Protection Quarantine and Storage (DPPQ&S) is responsible for implementation of Destructive Insect and Pest Act (DIPA), 1914 through Plant Quarantine (Regulation of Import into India) Order, 2003 to prevent entry, establishment and spread of exotic plant pests into India to safeguard agriculture, horticulture and forest tree plants. There are steps of invasion by alien organisms can be divided into four steps:

- **Introduction of invasive alien pest**
- **Establishment**
- **Spread**
- **Naturalization.**

Introduction of invasive alien pest: Some non-native species are imported intentionally for economic purposes, but many others arrive unintentionally in shipping containers, infesting fruits carried by tourists, or hidden in soil of imported ornamental plants. The introduction of invasives can occur through: Long distance migrations or movements (e.g. the brown planthopper, *Nilaparvata lugens* in rice), Transportation e.g. Parthenium along with wheat grains in India, Human activities and Aquarium plants e.g. water fern, water lettuce.

Establishment: Once the invaded species has overcome the environmental barriers in the introduced area then it establishes itself and at this stage populations are sufficiently large and the probability of local extinction due to environmental factors becomes negligible.

Spreading: The spreading of a species into areas away from initial sites of introduction requires that the introduced species have also to overcome barriers to dispersal within the new region which can cope with the abiotic environment and biota in the area.

Naturalization: Naturalization starts when abiotic and biotic barriers to survival rate are surmounted and when various barriers to regular reproduction are overcome. There are about 23 invasive insect pests reported in India (Table 1). The new invasive pest may thrive well in the invaded country due to lack of natural enemies in that area. This paper reviews the various biological control options for the invasive pests.

Natural enemies reported

A field surveys in Jammu & Kashmir and Himachal Pradesh reported that 4 species of parasitoids *viz*. *Aphytis proclia* Walker, *Azotus perspeciosus* Girault, *Encarsia perniciosi* (Tower) and *Teleterebratus perversus* Compere and Zinna and 4 predator species viz. *Chilocorus bijugus* Mulsant, *Coccinella septempunctata* Linnaeus, *Pharoscymnus flexibilis* Mulsant and *Sticholotis marginalis* Kapur as effective biocontrol agents of *Q. perniciosus* in Jammu and Kashmir, while in Himachal Pradesh they found only 1 species of parasitoid *i.e Aphytis proclia* Walker and 3 species of predators *viz*. *C. bijugus, C. septempunctata* and *P. flexibilis* attacking the pest. Many natural enemies were reported from Himachal

Table 1. List of important invasive pests of India.

Common name	Scientific name	Year of introduction	References
Woolly apple aphid	*Eriosoma lanigerum*	1889	Mishra (1920)
San Jose scale	*Quadraspidiotus perniciosus*	1921	Singh (2004)
Lantana bug	*Orthezia insignis*	1915	Muniappan *et al*. (1986)
Cottony cushion scale	*Icerya purchase*	1921	Singh (2004)
Potato tuber moth	*Phthorimaea operculella*	1906	Singh (2004)
Diamond back moth	*Plutella xylostella*	1914	Fletcher (1914)
Pine woolly aphid	*Pineus pini*	1970	Singh (2004)
Subabul psyllid	*Heteropsylla cubana*	1988	Jalali and Singh (1989)
Serpentine leaf miner	*Liriomyza trifolii*	1990	Singh (2004)
Coffee berry borer	*Hypothenemus hampei*	1990	Vega *et al*. (1999)
Spiraling whitefly	*Aleurodicus disperses*	1994	Palaniswami *et al*. (1995)
Silver leaf whitefly	*B. tabaci*	1905	Singh (2004)
Blue gum chalcid	*Leptocybe invasa*	2001	Singh (2004)
The coconut eriophid mite	*Aceria gurreronis*	1997	Singh (2004)
Papaya mealy bug	*Paracoccus marginatus*	2008	Jhala *et al*. (2008)
Cotton mealy bug	*Phenococcus solenopsis*	2005	Nagrare (2009)
Erythrina gall wasp	*Quadrastichus erythrinae*	2005	Faizal *et al*. (2006)
South American tomato leaf miner	*Tuta absoluta*	2014	Sridhar *et al*. (2014)
Fall armyworm	*S. frugiperda*	2018	Shylesha *et al*. (2018)

Pradesh such as *Aphytis* sp. *Nova proclia* (Walker), *Encarsia perniciosi* (Towers) and the *Teleterbratus perversus* Compere and Zinna. The effective Preator, *Chilocorus bijugus* Mulsant (Coleoptera : Coccinellidae) is reported by Rawat *et al*. (1993).

Management in India

For the suppression of the *Q. perniciosus* on apples, augmentative and inoculative releases of the two exotic parasitoids, *Encarsia perniciosi* (Tower) and *Aphytis proclia* (Walker)/*Aphytis diaspidis* (Howard) @ 2000/infested tree showed promising results. In Kashmir studies on the biology of *E. perniciosi* revealed the multiplication rate of parasitoids over 10 times and releases of *E. perniciosi* and *A. proclia* showed increase in parasitism from 8.9% to 64.3%.

Pine woolly aphid (*Pineus pini* Macquart; Adelgidae: Homoptera)

Status: Pine woolly aphid, *P. pini* was first introduced in India in the 1970s. In the Nilgiris hills of South India, the pest has caused severe damage to the *Pinus patula* plantations. As only the trial plantations had been established, the damage has been restricted to the *Pinus patula* and further spread of the pest has been contained by discontinuous planting of *P. patula*. This aphid has moved into new areas mostly by movement of infested planting stock.

Biological control: In USA (Hawaii) *Pineus* aphids have been controlled successfully by the introduction of the natural enemies such as predatory species *L. tapiae* and *L. nigraluna*, in Kenya by *Exochomus* spp., in Zimbabwe by coccinellid beetles and by *Exochomus quadripustulatus* and *Diomus pumilo* in Australia (fao.org).

San Jose scale (*Quadraspidiotus perniciosus* Comstock; Diaspididae: Homoptera)

***Status**:* It has possibly entered the Kashmir valley either in the late 19th or early 20th century. In Himachal Pradesh it was first reported in 1921 in Kullu valley and at Kotgarh (Shimla) in 1924 and then it has spread further to nearly all of the apple growing areas in the country. It is known to have high fecundity and fast multiplication rate especially in warmer areas. *Q. perniciosus* is a key pest of apple in certain hilly tracts of India.

Lantana bug (*Orthezia insignis* Browne; Orthezidae: Homoptera)

In 1915 it was introduced into India, Nilgiri region from Sri Lanka or West Indies. *O. insignis* native to Neotropical region, probably Guyana and neighbouring countries.

Hyperaspis pantherina **Fursch**

Management: *O. insignis* has a history of successful biological control in Hawaii and several African countries, through the introduction between 1908 and 1959 of the predatory South American coccinellid beetle, *Hyperaspis pantherina*. Successful biological control and protection of indigenous flora from the scale insect has also been achieved by *H. pantherina* on the island of Saint Helena in the South Atlantic Ocean; the action was successful in saving a field population of an 'Endangered (ER)' endemic gumwood species from extinction.

Cottony cushion scale (*Icerya purchasi* Maskell; Margarodidae: Homoptera)

Status: It was accidently introduced into India in 1921. In the Nilgiris and Pulneys there was a serious outbreak of Fluted or cottony cushion scale on citrus and other plants in 1941. The pest is now known to be present throughout country.
Management using bio control agents: *I. purchasi* populations have been suppressed in numerous countries with *Rodolia cardinalis*. In India *R. cardinalis* was introduced in 1929 in Tamil Nadu for control of *Icerya purchasi*. In Coorg and Bombay provinces in 1946 efforts were made to multiply and distribute some of its natural enemies, particularly the beetle *R. cardinalis* and the moth *Euzophera cocdphaga* and as a result of which the pest has been nearly eradicated and its spread to other provinces has been checked.

Woolly apple aphid (*Eriosoma lanigerum* Hausmann; Aphididae: Homoptera)

Status: Woolly apple aphid, *E. lanigerum* introduced in India during the 18^{th} century when apple cultivation had begun; but its first available record is from Conoor (South India) where the pest was reported to have almost destroyed every apple orchard. The pest had introduced on the imported apple stocks (Misra, 1920). *E. lanigerum* is distributed widely in India. It reproduces all year round on apple and crab apple. It is the most serious pest of apple in India, causing damage to root as well as the shoot systems. It imbibes the sap and infested plant parts become distorted badly due to formation of gall resulting into loss of the plant vitality and poor qualitative and quantitative yields. It was first recorded in Conoor during 1889 and in 1909 reported from Kumaun in Hills of Utter Pradesh (now in Uttarakhand) and in 1910 from Shimla. During 1920, it reached a pest status in India.

Natural enemies

Predators: Lady beetle, lacewing, syrphid fly, *Syrphus opinator* Osten Sacken, *Heringia calcarata* Loew, *Eupeodes fumipennis* Thomson, *Eupeodes americanus* Wiedemann, *Chrysopa nigricornis* Burmeister, *Coccinella transversoguttata* Brown and *Hippodamia convergens* Guerin-Meneville), *A. bipunctata*, *Harmonia axyridis (Pallas)*, *Coccinella septempunctata L.*, *Chrysoperla plorabunda*, *Hemerobius* spp., damselbugs, *Deraeocoris brevis* (Uhler) (Hemiptera: Miridae), spiders (Araneae), and earwigs (Dermaptera), *Coccinella novemnotata*, *Chrysopa coloradensis* Banks, *Deraeocoris brevis*.

Parasitoids: *Aphelinus mali* Haldeman

Entomopathogens: *Beauveria bassiana*, *Metarhizium anisopliae*, *Verticillium lecan*ii, *Neozygites fresenii*.

The effective predators for the management included *Coccinella septempunctata*, *Ballia ancharis*, *Chilomenes bijugus*, *Exochomus uropygialis*, *Coleophora sunzeti*.

Management: In India, an attempt to introduce *A. mali* from England was successful. It was originally released in Shimla and the parsitoid was later found to have colonized successfully in the entire apple growing areas of the country.

Potato tuber moth (*Phthorimaea operculella* Zeller; Lepidoptera : Gelechiidae)

Status: *P. operculella* introduced in India along with the potato seed brought from Italy in 1906. *Phthorimaea operculella* is now present in almost all the potato-producing states of India and is considered to be one of major pest of the Potato crop in the several states. The tuber damage in the storage has been found to range from 1 to 72.5% as reported in the endemic states. In Karnataka and Himachal Pradesh, losses upto 100% in the storage have been reported.

Management: In India, insecticides are commonly used to keep the pest below ETL with bio agents *Chelonis blackburni* and *Copidosoma kochleti*, *Chrysoperla zastrowi* sillemi, *Orius albidipennis* and *Labidura riparia* (Chandish *et al*., 1989).

Diamond back moth (*Plutella xylostella* Linn.; Plutellidae: Lepidoptera)

Status: In India, *P. xylostella* was reported in 1914 (Fletcher, 1914) on the cruciferous vegetables and is now the most devastating pest of the cole crops in the some of the states *viz.* Punjab, Haryana, Himachal Pradesh, Delhi, Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra and Karnataka. Occurrence of *Plutella xylostella* outbreak was reported in agro-climatic conditions of Aligarh, western part of Uttar Pradesh, India during September to the first fortnight of October in 2006 on cauliflower.

Management: It was concluded that the larvae and less frequently also the pupae of *P. xylostella* are sometimes attacked naturally by the pathogens and the two fungi, *Erynia blunckii* and *Zoophthora radicans* are predominantly associated with the pest. Other pathogens associated were one other entomophthoraceous fungus, a granulosis virus, one or possibly two nucleopolyhedrosis viruses and *Bacillus thuringiensis* var kurstaki. In Aligarh *Cotesia plutellae* was reported to be a dominant larval parasitoid while, *Oomyzus sokolowskii* parasitized relatively few pupae of Diamond back moth. It was also concluded that in India the dominant parasite is *Apanteles plutellae,* parasitizing up to 72% of the *P. xylostella* larvae. The major mortality factor in 1st and 2nd instar larvae is parasitism by *A. plutellae,* predacious ants, birds, spiders and rainfall. The major mortality factor in pupal stage is parasitism by the eulophid *Tetrastichus sokolowskii* (Cherian and Basheer, 1938). Cherian and Basheer (1938) observed 59.9% parasitization by *Brachymeria excarinata* Gahan and 18.2% parasitization due to *Tetrastichus* *sokolowskii* Kurdj.

Spiraling whitefly (*Aleurodicus dispersus* Russell; Aleyrodidae: Homoptera)

Status: In India this species was first recorded at Nedumangad (Trivandrum) (Thiruvananthapuram, Kerala) in 1994 in the month of March infesting heavily wild tapioca and wild rubber (Jhala *et al*., 2008). In December l994, it was noticed infesting a wide range of the host plants such as guava, mulberry, wild tapioca etc. from Calicut, Kunnamkutam, Trichur, Alwaye, Ernakulam, Sherthalai, Alleppey, Kayamkulam, Ouilon, Attinkal, Trivandrum, Neyyattinkara, Parasala and Kaliakkavilai of Kerala and Marthandam, Thiruvattar, Thuckkalay, Nagercoil and Kanyakumari of Tamil Nadu (David and Regu, 1995). *A. dispersus* is highly polyphagous pest and has been reported on 253 host plants in country. Further, the dense populations of this pest is known to cause premature leaf drop and further the honeydew produced by them serves as a substratum for growth of sooty mould, leading to abandoned crops.

Management: Predators identified were *Nephaspis oculata*, *Delphastus pusillus* and *Coccinella septempunctata* and Parasitoids identified were *Encarsia erimicus* and *Encarsia formosa*. It was reported the occurrence of *Encarsia haitiensis* Dozier (Hymenoptera: Aphelinidae) in Bangalore, Karnataka and also showed that the per cent parasitism was influenced by the host plant. The per cent parasitism ranged from 0.00 to 38.88 on different host plants being highest on *Cassia siamea*. Ramani (2000) reported both *E. haitiensis* and *Encarsia Guadeloupe* Viggiani (Hymenoptera: Aphelinidae) from Lakshadweep Islands (India). The latter species has since then been introduced into mainland India around Bangalore and has well established and is spreading. The two native predators, *Axinoscymnus puttarudiahi* Kapur (Coleoptera: Coccinellidae) and *Cybocephalus* sp. are able to discriminate between the parasitized and healthy larvae and pupae (Ramani, 2000). Both the species of parasitoids and the native predators are maintaining the pest under check now wherever they occur.

Coffee berry borer (*Hypothenemus hampei* Ferrari; Scolytidae: Coleoptera)

Status: *H. hampei* was first reported in India from Gudalur in the Nilgiris of Tamil Nadu. It was introduced accidentally in the country, probably through seeds brought by the refugees from Sri Lanka or through illegally imported seeds of coffee. Over the years it has gradually spread to more areas and is now prevalent in almost all the coffee growing zones in the States of Karnataka, Kerala and Tamil Nadu (88% of the coffee area in India). It has not spread to the Non-traditional areas of Andhra Pradesh and Orissa and the North-Eastern India (12% of coffee area in India).

Management: Several parasitoids that are recorded, three were introduced into India. They are *Prorops nasuta* Waterston, *Cephalonomia stephanoderis* Betrem both from Mexico and *Phymastichus coffea* Lasalle from Colombia through the efforts of NBAII, Bangalore and the Coffee Board. The isolated fungus *Beauveria bassiana* (Balsamo) Vuillemin from dead and moribund coffee berry borers and cultured on yeast extract peptone supplemented liquid medium. A suspension of the isolate (Bb2) was prepared in the sterile water. The laboratory studies were conducted on coffee berry borers by applying conidial suspensions at a dosage rate of 1×10^6 conidia ml^{-1}. Mean insect mortality rates of 69.3, 86.9 and 95.3% occured at 50, 70 and 90% RH conditions, respectively. They also conducted field experiments in the coffee plantation area in Kodagu district of Karnataka, and it was observed that under the favourable environmental conditions (27± 29°C; 82±91% RH; 10±15 inches rainfall per year), the fungus required only eight days to colonize and kill the target pest. A mean insect mortality level of 61.2% was obtained after eight days of spraying. A maximum of 75.6% mortality was recorded after 24 days of spraying. Ten isolates of the entomopathogenic fungus *Metarhizium anisopliae* in the laboratory for infectivity to the coffee berry borer *H. hampei*. The adult beetles were treated with four spore concentrations (10^5, 10^6,10^7 and 10^8 per ml). It was reported that eight isolates caused more than 90% infection at the highest spore load.

Silver leaf white fly (*Bemisia tabaci* Bellows; Aleyrodiadae: Homoptera)

Status: The first record of presence of *B. tabaci* in India was in 1905 from cotton. Whitefly, *B. tabaci* is the major sucking pests on cotton in northern and southern India, while the whiteflies are the predominant sucking pests on brinjal in eastern India. Huge populations of whiteflies were recorded during 2015 in Punjab, Haryana and Rajasthan leading to considerable economic losses to the farmers.
Management: A field survey during 2016 and 2017 in different cotton growing districts of Punjab reported the presence of Sixteen species of natural enemies including 7 species of insect predators (*Coccinella septempunctata* Linneaus, *Cheilomenes sexmaculata* (Fabricius), *Brumoides suturalis* (Fabricius), *Serangium parcesetosum* Sicard, *Chrysoperla zastrowi* sillemi (Esben-Peterson), *Zanchius breviceps* (Wagner), *Geocoris* sp.); 2 species of parasitoids (*Encarsia lutea* (Masi), *Encarsia sophia* (Girault & Dodd)) and 7 species of spiders (*Neoscona* sp., *Argiope* sp., *Oxyopes* sp., *Thomisus* sp., *Runcinia* sp., *Hyllus* sp., *Chrysilla* sp.). Among these, *Chrysoperla* was the found to be predominant species. The parasitization by *Encarsia* spp. on whitefly in different cotton growing areas of Punjab ranged from 1.5 to 9.1 %. Srinivasa *et al.* (1999) reported the occurrence of *Encarsia haitiensis* Dozier in Bangalore, Karnataka and also showed that the per cent parasitism was influenced by the host plant. The per cent parasitism ranged from 0.00 to 38.88 on different host plants being highest on Cassia siamea Lamk. (Fabaceae). Ramani (2000) reported both *E. haitiensis* and *E. guadeloupe* Viggiani from Lakshadweep Islands (India). The latter species has been introduced into mainland India around Bangalore and has well established and is spreading. The two native predators, *Axinoscymnus puttarudiahi* Kapur (Coleoptera: Coccinellidae) and *Cybocephalus sp.* are able to discriminate between the parasitized and healthy larvae and pupae (Ramani, 2000). Both the species of parasitoid and the native predators are maintaining the pest under check now wherever they occur.

Serpentine leaf miner (*Liriomyza trifolii* Burgess; Agromyzidae: Diptera)

Status: The serpentine leaf miner, *Liriomyza trifolii* (Burgess) was accidentally introduced into India from American sub-continent along with *Chrysanthemum* cuttings. In India, *L. trifolii* damage was first reported from castor (*Ricinus communis* L.) in 1992. Serpentine leaf miner *L. trifolii* gradually attaining the major pest status in different region of the country and reported to cause 35% losses in tomato crop. The Serpentine leaf miner, *L. trifolii* entered India during 1990-1991.

Management: Among the parasitioids *Diglyphus begini* (Ashmead), *D. intermedius* (Girault) and *Chrysonotomyia punctiventris* (Crawford) seems to be promising in exerting practical control of the pest under greenhouse conditions in different parts of Europe. In India, parasitism by the indigenous parasitoids ranges from 0-39 per cent in Bangalore on tomato and cucumber to 49 per cent in Gujarat on castor and *Hemiptarsenus varicornis* (Girault) is the most predominant one (Kapadia *et al*., 1997). *D. begini* was introduced into India from California, USA and field released in the vegetable gardens around Bangalore during 1997 after laboratory tests. Reports indicate that it has not established in the field. 45 species of Chalcidoidea and Braconidae reported on larval and pupal stages of *L. trifolii* from different parts of world. The parasitism in some areas may be as high as 51-98 per cent (Neuenschwander *et al*., 1987).

Papaya Mealy bug (*Paracoccus marginatus*; Pseudococcidae; Hemiptera)

Status: *Paracoccus marginatus* was first reported in India in Tamil Nadu in 2008. It assumed the status of a major pest in India in 2009 when it caused severe damage to economically important crops and huge losses to farmers in Coimbatore, Erode, Tirupur and Salem districts of Tamil Nadu. It has a wide host range. In Kerala, during 2010-12 periods, 95 host plants were recorded belonging to 39 plant families. Highest number of host plants of *P. marginatus* was recorded under the family Euphorbiaceae. Heavy population build up was recorded on 44 host, moderate incidence on 27 plants and on 21 hosts, the infestation severity was low. Spatial distribution studies showed that the variance to mean ratio was the highest on *Manihot esculenta* Crantz (>100) and lowest on *Phyllanthus amarus* Schumach & Thonn. (0.63).

Management: The pest was successfully managed through the intervention of classical biological control wherein *Acerophagous papayae* was imported from USA. It was observed that biological control of papaya mealybug by releasing parasitoid *A. papayae* at 100 numbers per hectare proved superior to unreleased field in causing reduction in mealybug population besides recording higher level of parasitoid activity. The mean initial mealy bug population was 48.4 in parasitoid released field and 46.65 in unreleased field. The population of mealy bugs at 15 and 30 Days after Release (DAR) was found to be 28.95 and 16.45 in parasitoid released field respectively. The pre-release mean population of parasitoid was 1.69 in released and 1.45 in unreleased field. At 30 DAR the population of parasitoid count was found to be 5.10 in released and 2.25 in unreleased field.

Subabul psyllid (*Heteropsylla cubana* Crawford; Psyllidae: Homoptera)

Status: The tree was almost pest free in India until 1988, when the leucaena psyllid, *Heteropsylla cubana*, appeared in Chengalpetu (Tamil Nadu) and caused severe defoliation and extensive death of young trees. By 1990, it had attacked all the *Leucaena* plantations in the country.

Management: Natural enemies include the beetles *Menochilus sexmaculatus* (E), *Scymnus gracilis* Motschulsky, *Harmonia* sp. (Coccinelidae), and *Paederus fuscipes* Curtis (Staphylinidae); the hemipteran *Cardiastethus* sp. (Anthocoridae); the hymenopteran *Ropalidia montana* Carl (Vespidae); mantids; reduviids; mirids; syrphids; dragonflies; chrysopids; and spiders. These generalist predators have not provided appreciable control of *H. cllbana*. The presense of *Menochilus sexmaculatus*, *Scymnus* sp. and the exotic *Curinus coeruleus*, which was released by the National Biological Control Centre, were common on the psyllid population. Other natural enemies recorded were *Menochilus sexmaculatus* (Fabricius), *Scymnus sp*., *Curinus coeruleus*, *Pantala flavescens* (Fabricius), *Ischiodon scutellaris* (Fabricius), *Stegodyphus socialis* Muslont *Stegodyphus sarasinomm*. A number of native general predators such as *Cheilomenes sexmaculatus* (Fabricius) (Coleoptera: Coccinellidae) and *Pantala flavescens* fed on the outbreak populations of the psyllid but they did not exercise the required control. In 1988, the ladybeetle, *Curinus coeruleus* Mulsant from Mexico it was introduced into India for the biological suppression of *H. cubana*. The predator has since successfully established in Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu

Coconut eriophid mite (*Aceria gurreronis* Keifer; Eriophyidae; Arachnida)

Status: In India, the mite was reported from many coconut gardens of Kerala during 1997-98 and in Karnataka and Tamil Nadu during 1998-99 and has drawn national attention as a threat to the coconut plantation. Coconut palm, *Cocos nucifera* Linn. is an important plantation crop grown in India. Among different pests infesting the crop, eriophyid mite, *Aceria guerreronis* (Keifer) is a serious pest in many coconut growing areas in India. The rapid outbreak of this pest in coconut plantations endangered the copra industry in India, reducing coconut yields and economic profits. This has drawn the attention of farming communities and researchers. To date the most intractable and most damaging pest of coconut fruit is by far the eriophyid mite, *A. guerreronis*, commonly called "coconut mite". In a survey conducted in 1999 at Kerala, nearly 42 per cent of plants were affected and estimated yield loss was around 22 per cent. The percentage of reduction in nut weight due to mite infestation was estimated as 2.12 per cent.

Management: The fungus *Sporothrix fungorum* caused epizootic development of *A. guerreronis* in Karnataka. Two natural enemies are *Neoseiulus baraki* and *Hirsutella thompsonii*. Natural occurrence of *H. thompsonii* contributed to 4.93 per cent. Pathogenicity to coconut eriophyid mite was proved for two species of *Hirsutella*, *H. thompsonii* and *H. kirchnerii*. The other non-specific fungi found to be pathogenic to mites were *Acremonium strictum*, *A. incoloratum*, *Fusarium lateritium*, *F. verticillioides*, *Paecilomyces fumosoroseus* and *P. lilacinus*. The wide spectrum of fungal pathogens associated with *A. guerreronis* indicates the significant role played by them in the natural suppression of the pest.

Cotton mealy bug (*Phenococcus solenopsis* Tinsley; Pseudococcidae; Hemiptera)

Status: In India, it has been recorded as a serious pest on cotton and is widespread throughout cotton-growing states of the country, viz., Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andra Pradesh, Karnataka and Tamil Nadu (Nagrare *et al*., 2009).Roving survey carried out in Baroda during November 2006 revealed that 25-30% cotton fields were infested with mealybug and 20-90% plants were adversely affected causing a reduction of 50% yield in highly infested fields (Jhala *et al*., 2008). The earliest *P. solenopsis* infestations in India were recorded in 2005 in Gujarat state
Management: Prasad *et al*. (2011) conducted surveys in cotton fields during 2007-09 in Haryana, Rajasthan and Punjab in the North zone and Madhya Pradesh, Maharashtra and Gujarat in the Central zone indicated that *Aenasius bambawalei* Hayat (Chalcidodea: Encyrtidae), an indigenous parasitoid, played a key role in reducing the insect pest infestation. The parasitoid was first recorded in Delhi in July 2008 and by 2009 it was found in most of the cotton growing districts of North and Central zones. Its natural parasitization on *P. solenopsis* could reach more than 90% at many locations. This is the most successful example of biological control of mealybug. Along with this parasitoid, another parasitoid, *Promuscidea unfasciativentris* Girault (Chalcidodea: Aphelinidae), was also recorded at most of the locations in smaller proportions.

South American tomato leaf miner (*Tuta absoluta* Meyrick; Lepidoptera: Gelechiidae)

Status: In India, *T. absoluta* was first reported during October, 2014 infesting tomato fields in Pune, Ahmednagar, Dhule, Jalgaon, Nashik and Satara districts of Maharashtra.
Attacks: *Nesidiocoris tenuis* (Reuter) was found predating on eggs and early instars of *T. absoluta* under field conditions. Presence of this natural enemy feeding on whitefly in tomato ecosystem in India was earlier reported. *Trichogramma achae* was also found to attack eggs of *Tuta absoluta*.

Blue gum chalcid (Gall making insect), *Leptocybe invasa* (Eulophidae: Hymenoptera)

Status: In India it was first reported during 2001 from Karnataka. In Karnataka, the gall wasp was reported to be on an attacking spree and damaged 2.5 M eucalypt saplings in the nurseries of two major wood based industries (West Coast Paper Mills and Harihara Polyfibres).
Management: The National Bureau of Agriculture Insect Resources (NBAIR), Bangalore imported *Quadrastichus mendeli* Kim & La Salle and Selitrichodes kryceri Kim & La Salle parasitoids of *L. invasa* into India. They under quarantine conditions conducted host specificity studies and thereafter recommended its release in the country during 2011-12 (Shylesha, 2012). It is reported, the utilization of native parasitoids *viz. Megastigmus dharwadicus* Narendran and Vastrad and *Aprostocetus gala* Walker for biological control of eucalyptus gall wasp, *Leptocybe invasa* Fisher and LaSalle (Hymenoptera: Eulophidae). Two native parasitoids multiplied in the greenhouse were released in a severely affected eucalyptus plantation spread over an area of 1000 ha. A total of 14,000 heavily parasitized galled seedlings, 1400 *M. dharwadicus* and 300 *A. gala* were distributed over a period of six months. The per

cent parasitization by these native parasitoids was ascertained before distribution of galled seedlings. Though there was a gradual increase in per cent parasitization, the reduction in gall incidence was not evident up to three months. However, drastic reduction in gall incidence and pest emergence accompanied by very high per cent parasitization was evident within eight months. Post release evaluation conducted during June 2011 and May 2012 indicated the successful control of the pest.

Erythrina gall wasp (*Quadrastichus erythrinae* Kim; Eulophidae; Hymenoptera)

Status: *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae) In India, it was first recorded from Kerala in 2005. It is a major invasive pest on *Erythina* spp. in black pepper plantations of Kerala and Karnataka. The Erythina gall wasp was first noticed in 2005 and 2006 and spread to all districts of Kerala and Karnataka and also recorded from Maharashtra. Nearly 60 per cent damage of Erythina plants were observed in Wayanad District of Kerala during 2006. The damage in Erythina plants directly affects production of black pepper in these areas as Erythina plants are used for trailing Black Pepper and Vanilla. *Eurytoma erythrinae* and *Aprostocetus exertus* as a new parasitoid of Erythrina gall wasp, *Quadrastichus erythrinae*.

Fall armyworm (*S. frugiperda* J. E. Smith)

Status: In India, the yield losses due to *S. frugiperda* infestation in maize have been estimated to be varied from 12.4 to 65.7 per cent in Northern Karnataka. Severe damage was noticed in Chikkaballapur, Shivamogga, Hassan, Davanagere and Chitradurga in July–August 2018 (Shylesha *et al*., 2018).
Attacks: Bioagents from diverse groups including predators, parasitoids and entomopathogens have been recorded against *S. frugiperda*. It is known to be attacked by more than 150 parasitoid and parasite species belonging to 14 families within orders Hymenoptera, Diptera and Nematoda.

Predators

Several generalist predators are known to feed on different stages of *S. frugiperda*. Some of the important predators are striped earwig, *Labidura riparia* (Pallas), spined soldier bug, *Podisus maculiventris* (Say), insidious flower bug, *Orius insidiosus* (Say) and various ground beetles. Further, vertebrates such as birds, skunks and rodents also have been reported to consume larvae and pupae of *S. frugiperda*. In India, three species of predators, *viz*. *Harmonia octomaculata* (Fabricius), *Coccinella transversalis* (Fabricius) and *Forficula sp*. have been recorded from maize fields in Tamil Nadu. In North-East states of India, about 12 predator species have been found associated with *S. frugiperda* including *Eocanthecona furcellata* Wolff, *Andrallus spinidens* (Fabricius), *Cosmolestes* sp., *P. maculiventris*, *Ropalidia brevita* Das and Gupta, *Polistes* cf. *olivaceus* (De Geer), *Cicindela* spp., *Rhene flavicomans* Simons, *Marpissa* sp., *Oxyopes birmanicus* Thorell, *Lycosa* sp. and indeterminate earwig in maize agroecosystem.

Conclusion

Biocontrol has long been considered as an alternative to pesticidal strategies for invasive pest management but its results and level of use globally remain modrate and inconsistently. Biological control is eco- friendly and active means of mitigating insect pest and their effect through use of natural enemies. The objective of biological control is to promote the technology and science. It is a technique of managing pest including insects, fungi, nematodes, mites etc by using other micro-organisms.

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Chapter [22]

Hydrobiological characteristics of Ganga River at Barrage Bijnor, Uttar Pradesh, India

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Abstract

Biodiversity is the variety of life on the Earth, it includes all organism's species, and populations. The present study reports hydrobiology and occurrences of organochlorine pesticides (OCPs) in the Ganga river barrage at Bijnor Uttar Pradesh. Samples were monitored for 5 major OCPs, including hexa-chlorocyclohexanes (HCHs), Aldrin group, and DDTs. The hydrochemical characterization evaluates the quality of water for irrigation purpose. The outcomes analyze the pH of water, Total Dissolve Solids (TDS) values extend-ing from 115 to 676 mg/L, averaging 271 mg/L. Anion and cation concentration (mg/L) were $HCO_3^- > SO_4^{2-} > Cl^- > CO_3^{2-}$ anions and $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ cations. Maximum hydro chemicals were in the form of bicarbonates $Ca–HCO_3$ type. The characterization was different from upper and downstream of the main stream. Analysis shows variations at different sites and seasons thus affecting the habitat, growth, reproduction and migration of aquatic flora and fauna. The quality of water is suitable at a particular season for bathing and irrigation purposes at Ganga Barrage, Bijnor Uttar Pradesh. Bijnor Ganga Barrage fauna is facing the threats of categories like variation in nutrient enrichment, hydro-logical modifications, chemo geodiversity, habitat loss, degradation, and pollution, dominancy of invasive species, extreme flood and draught.

Keywords Chemo-geo-diversity, Ganga, Hydrobiology, Organochlorine pesticides

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Introduction

Himalaya is the birth place of many large rivers *i.e.,* Ganga, Yamuna and Ram Ganga etc. Surface water resources assume a significant job in the worldwide carbon cycle by putting away, moving, or changing inorganic and natural (natural) carbon segments along the hydrologic continuum connecting the land and seas (Kempe *et al*., 1984; Cole *et al*., 2007; Battin *et al*., 2009). Late blends have given more prominent appraisals to the riverine transport of decomposed organic carbon and particulate natural carbon and the ex-change of CO_2 between the climate and surface water (Raymond *et al.,* 2013; Wehrli *et al.,* 2013; Ward *et al.,* 2017). Analysis is meager for some stream frameworks in India, leaving many vulnerable sides in worldwide combinations of riverine carbon transport and discharge. Albeit Asian waterways have been assessed to represent up to 40–50 % of the worldwide inorganic and natural carbon transitions from the land to the seas (Degens *et al.,* 1991; Schlunz *et al.,* 2000), the absence of right information and poor spatial spread monitoring have compelled our capacity to appraise the commitments of Asian stream frameworks to the worldwide riverine carbon motions in CO_2 emission specifically (Li and Bush, 2015). For example, getting CO_2 information estimated in Indian streams was recommended as a top need to diminish the huge vulnerability in assessing the worldwide riverine CO_2 out-gassing (Lauerwald *et al.,* 2015).

The hydrochemical structure of a watershed is demonstrative of nature of the zone it moves through. An examination of the hydrochemical water can decide the geochemical wellspring of the waterway solute and related data, including enduring and atmosphere of the watershed (An *et al.,* 2015). There are numerous sources of contamination in surface water, for example, enduring of earthly shakes, barometrical precipitation, and anthropogenic sources (Moon *et al.,* 2007). The hydrochemical qualities of streams starting from the Himalaya resion are changing with environmental change and expanding human exercises (Zhang *et. al.,* 2015 and Zhang *et al*., 2019). In any case, numerous past hydrochemical concentrates on the headwaters of streams starting from the Gadgetry have been fundamentally focused on Ganga waterways, and hydrochemical concentrates (Wu *et al.,* 2008; Jiang *et al.,* 2015 and Wu *et al.,* 2005). An exhaustive analysis of the hydrochemistry of the source area of the Ganga River has not yet been performed. In this manner, so as to explain the attributes of the riverine water science in the River bowl, more examinations ought to be done. The Ganga River and its tributaries are significant hotspots for irrigation and are significant wellsprings of drinking, and house hold water for individuals living in the stream bowl. Right now, broad investigation dependent on water tests was done to portray the hydrochemistry of the standard of the Ganga River and its tributaries, and an evaluation of water quality for bathing and irrigation.

Biodiversity is the variety of life on Earth, it includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems. Aquatic biodiversity can be defined as the variety of life and the ecosystems that make up the freshwater and tidal regions of the world and their interactions. Aquatic biodiversity is greatest in tropical latitudes. About 22000 species of fishes have been recorded in the world; of which, about 11% are found in Indian waters. Out of the 2200 species so far listed, 73 (3.32%) belong to the cold freshwater regime, 544 (24.73%) to the warm fresh water's domain, 143 (6.50%) to the brackish waters and 1440 (65.45%) to the marine ecosystem (Kellerman *et al.,* 2014). India has great diversity in its Geo-climatic conditions. Biodiversity is the varied and differences among living organisms of terrestrial, marine and other aquatic ecosystems and the ecological complexes associated with them. India has great diversity in its geo-climatic conditions. Thus, there is great diversity in India's forest, wetlands, mangroves wildlife and marine areas. The richness in fauna and flora makes it as one of the 12 mega-biodiversity countries of the world (Conserving Biodiversity, 1992). Fresh-water habitats are threatened by many factors, including pollution from industry, increased acidification, and agricultural runoff containing residues of fertilizers or pesticides. In addition, the building of dams destroys many river ecosystems. Development can harm aquatic habitats or remove them altogether, as when marshy areas are filled. In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done (Joshi *et al*., 2017). Aquatic ecosystems also are particularly fragile because the disturbance of a watershed can affect multiple components downstream, including rivers, lakes, estuaries, and oceans. Perhaps the largest threat to ocean biodiversity is overfishing. In addition to depleting commercial species of fish, bivalves, and crustaceans, many fishing methods cause the needless deaths of non-commercial fish species as well as numerous reptiles, birds and marine mammals. The diversity in terrain, topography, climate and soils are able to sustain diverse forms of life. Thus, there is great diversity in India's forest, wetlands, mangrove wildlife and marine areas. The richness in fauna and flora makes it as one of the 12 mega-biodiversity countries of the world (Wang *et al*., 2019).

Study area

The Origin of Ganga is Gangotri glacier present in Western Himalayan region in Uttarakhand, India. The river Ganga or Ganges is 2,525 km long and flows to the south- east through the Gangetic Plain of the North India into the Bangladesh where it merges into the Bay of Bengal. The altitude of river Ganga ranges from 8848 m in the high Himalayas to the sea level in coastal deltas of India and Bangladesh. The Ganga basin is the home to more than 450 million people and as a result, river Ganga is in strong demand for the domestic and irrigation uses. Fishing along the river yields economy and serves nutritional needs. Ganga waterway and its significant tributaries at Uttarakhand, Uttar Pradesh and Bihar states speak to the investigation region. After passing the Uttarakhand holy river Ganga enters in Uttar Pradesh and Ganga Barrage, Bijnor is the first famous public spot where Hindus take a holy dip in Ganga. Ganga Barrage, Bijnor was testing and sampling site as shown in Figure 1.

Water sampling and analysis

Water sample was collected from sites Ganga Barage, Bijnor (Uttar Pradesh, Figure 1) between the December 2017 to August 2019. Two samples were taken from the site during each sampling campaign.

Figure 1. Sampling location of the river Ganga.

One sample was collected for Ogranochlorine pesticide analysis, while the second sample was collected for Hydrochemical Analysis, Anion and cation concentration (mg/L) were HCO_3^- > SO_4^{2-}> Cl^-> CO_3^{2-} anions and Ca^{2+} > Na^+ > Mg^{2+} > K^+ cations. Sampling bottles were rinsed with river water and were carefully filled to overflowing, without trapping air bubbles in sealed bottles. The samples were transported in cool-box with ice packs and subsequently stored in a refrigerator at 4°C until further analysis. All the samples were transported on ice and kept under refrigeration until performance of laboratory analysis. The pH, water temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured in situ using a Horiba U50 (HORIBA Ltd., Kyoto). Ca^{2+}, Mg^{2+}, K^+, Na^+, HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^- were measured at the. Concentrations of HCO_3^- and CO_3^{2-} were measured by titration using 50-mL acid burettes (DZ/T0064.49-93, 1993). The concentration of Cl^- was determined by titration using 50 mL brown acid burettes (DZ/T0064.50-93, 1993). The concentration of SO_4^{2-} was determined by UV/VIS spectrophotometer (DZ/T0064.65-93, 2015). Concentrations of Ca^{2+}, Mg^{2+}, K^+, and Na^+ were analyzed by inductive coupled plasma atomic emission spectrometry (HJ776-2015)

All chemicals used during the study were analytical grade procured by Merck. Reagents and calibration standards for physico-chemical analysis were prepared using double glass distilled water. The glass-wares were washed with dilute nitric acid followed by distilled water. Standard was procured from Sigma Aldrich. The working standards of pesticides were prepared in n-Hexane and were stored at -20 °C.

Physico-chemical parameters

Alkalinity, chloride and hardness were measured by titration method in the laboratory. Nitrate and ammonia were measured by selective ion electrode (Thermo and HACH, respectively), while TOC was analyzed on TOC analyzer (Shimadzu). EC, pH, DO and total dissolved solids (TDS) were measured onsite using portable meters. pH, electrical conductivity (EC), alkalinity, chloride hardness, dissolved oxygen (DO), total organic carbon (TOC), nitrate, and ammonia as per APHA (1998).

Extraction

Before GC analysis all samples were filtered using 0.45μm glass fiber filter to remove suspended impurity and were extracted without any pH adjustment. A liquid extraction (LLE) method, using n-hexane as solvent, was used for extraction of pesticide residues (APHA-1998). Sample beaker was shaken and filtered sample was transferred to a separating funnel (1000 mL cap.). It was mixed with 20 g of sodium chloride and 40 ml of n-hexane. The sample was shacked properly for 60 min and the hexane layer was separated with the help of separating funnel. One more extraction was done with 25 ml n-hexane and the combined hexane extract was treated with 8 g anhydrous Na_2SO_4 to remove traces of moisture. The moisture free (dehydrated) n-hexane was rotary vacuum evaporated to a small volume and transferred to an airtight test tube followed by evaporation of solvent under a mild stream of nitrogen to 1.0 ml. The concentrated samples were ready to gas chromatograph (GC) analysis.

Organochlorine pesticide OCPs analysis

The contamination of OCPs was analyzed by Thermo Trace GC Ultra gas chromatograph equipped with 63-Ni micro-electron capture detector (GC-ECD) and an auto sampler. The column specifications and operating conditions are Column DB-5, fused silica capillary with 30 m × 0.25 mm ID, thickness 0.25 μm, carrier gas Helium with 1.0 ml/ min makeup with 30 ml/min N, oven programming 90-150°C rising rate 15°C/min, 150-220°C rising rate 3°C/min and 220-270°C rising rate 5°C. Injection volume 2.0 μl, Injector temperature 250°C, Detector temperature 280°C.

Status of physico-chemical parameters

Water quality in mountainous stretch Ganga is very good, with high DO levels Avg. 8.17∓0.4, low EC, TDS and TOC, indicating no significant contamination pollution. When Ganga enters in Uttar Pradesh the first station is Bijnor before this many small rivers and the sub-basins are merge in Ganga. The STPs reduce 61–93 % organic loadings and half of trace contaminants present in the sewage (CPCB-2009). Domestic sewage is the major contributor of pollution in this stretch. The water quality in the stretch is affected from the Rishikesh (Uttarakhand) by domestic, industrial organic and inorganic west and agricultural runoff. The Dissolve Oxygen (DO) levels in all the samples were in the range of 4.9-7.9 mg/ L (DO_{avg} (mg/L) = 5.6∓1.2), however this zone has some of the worst polluted stretches, but due to high monsoonal flow, the river water quality appeared good from the water quality data obtained during this sampling campaign (Table 1).

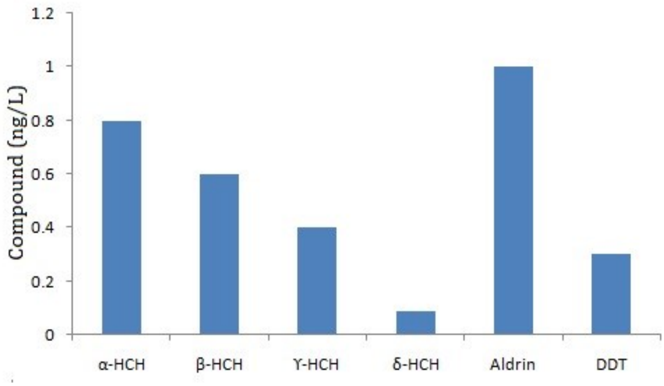

Figure 2. Comparison of reported organochloride pesticides (OCPs) levels in the Ganga barrage Bijnor.

Organochlorine pesticides

Different types of organochlorine pesticides are widely used in agricultural sector all over the Ganga basin (Rehana *et al.*, 1995; Nayak *et al.*, 1995; Malik *et al.*, 2009). Beside the runoff from agricultural fields, the agricultural practices in the dry bed of the rivers, which are common in India (Hans *et al.*, 1999), also, add pesticides to the river during monsoon. The OCPs levels in Bijnor UP, Ganga garage are shown in Figure 2. In this stretch concentration of all the targeted OCPs varies from 0.2 to 1.00 ng/ L.

Major elements

In terms of variation, the pH of the middle of the main stream of the Ganga was the highest in the whole catchment every year (2017-2019). The pH of all analyzing sample was slightly alkaline range between from 7.89 - 8.42 with an average of 7.2. The water temperature measured in situ was 9.42-29.07 °C in 2017, 9.42-28.82 °C in 2018, and 8.87-30 °C in 2019. Total dissolve solid (TDS) of Ganga water sample 85 mg/L to 453 mg/L, with an average of 250 mg/L. TDS of the Ganga water of the main stream of the Ganga River was the highest in the whole catchment in 2017, 2018, and 2019. Electrical conductivity (EC) varied from 125 µS/cm to 425 µS/cm, averaging 282 µS/cm. Increasing order may have caused this phenomenon. In addition, the EC of the main stream of the Ganga was the highest in the whole catchment in 2017, 2018, and 2019. pH, TDS and electrical conductivity of the main stream of the Ganga River shown in Table 1.

Fresh water biodiversity

Freshwater ecosystems are a subset of Earth's aquatic ecosystems. They include lakes, ponds, rivers, streams, springs, bogs, and wetlands. Limnology is a branch of freshwater biology and a part of hydrobiology. Freshwater habitats can be classified by different factors, including temperature, light penetration, nutrients, and vegetation (Wetzel *et al.*, 2001). Temperature in fresh water habitats does not show much range of variation, due to several unique thermal properties of water. Turbidity of water

Table 1. Summary statistics of hydrochemical compositions from the Ganga barrage Bijnor.

Parameters	Mean	Standard Deviation	Min	Max
Temperature (°C)	23 °C	5 °C	9.4 °C	30 °C
pH	7.89	2.35	7.20	8.42
EC (µS/cm)	382	165	325	425
TDS (mg/L)	368	188	385	453
K^+(mg/L)	2.87	1.08	2.32	5.36
Na^+(mg/L)	43.45	15.88	39.12	55.32
Ca^{++}(mg/L)	73.54	16.52	58.48	88.02
Mg^{++}(mg/L)	28.85	8.42	22.33	35.05
Cl^- (mg/L)	21.45	5.64	17.36	25.66
SO_4^{--} (mg/L)	122.62	32.88	76.05	165.69
HCO_3^- (mg/L)	216.13	71.69	144.13	288.07
TOC (mg /L)	4.4	1.2	3.1	5.8
Nitrate (mg /L)	2.4	0.9	1.2	3.6
Ammonia (mg /L)	5.2	1.8	2.7	8.9
Hardness (mg /L)	158.7	16.7	148	169.2
Alkalinity (mg /L)	171.2	22.3	152	192.4
DO (mg /L)	5.6	2.6	4.9	7.8

depends upon the kinds and amount of suspended material like silt, clay particle and living organism etc. Turbidity affects the penetration of light and thus is important factor in the distribution of organisms. Large rivers have comparatively more species than small streams. Many relate this pattern to the greater area and volume of larger systems, as well as an increase in habitat diversity. Some systems, however, show a poor fit between system size and species richness. Organisms in fresh water habitats are generally classified in to following manner: on the basis of their major niches, their life habit and sub habitat they are autotrophs (producers), phagotrophs (macroconsumers), saprotrophs (decomposer or microconsumer), benthos (bottom), periphyton (attached to other plants), planktons (floating), nekton (swimming) and neuston (resting or swimming on surface). Freshwater ecosystems can be divided into lentic ecosystems (still water) and lotic ecosystems (flowing water).

Lentic communities: Lentic communities are found in three distinct zone i.e., littoral, limnetic and profundal. Producers like, rooted and benthic plants (Nymphaea, Nelumbo), mainly seed plants, rooted hydrophytes (Typha, Scirpus, sagittaria, Eleocharis etc.), floating green plants, the phytoplankton, mainly the algae are distributed in these zones. These algae are diatoms, green algae, including unicellular forms as desmid, filamentous (attached or floating) as species of *Spirogyra, Oedogonium, Cladophora, Chara* etc., and various colonial forms as *Volvox, Hydrodictylon etc;* blue green algae, which are unicellular and colonial. In littoral zone the consumer is animal in which vertical rather than horizontal zonation is more striking. The zooplankton represents a few species but their number is large. Copepods, cladocerans and rotifers are chiefly present. Common forms are other vertebrate taxa inhabit lentic systems as well. These include amphibians (e.g., salamanders and frogs), reptiles (e.g., snakes, turtles, and alligators), and a large number of waterfowl species (Moss *et al*., 1998). Most of these vertebrates spend their time in terrestrial habitats and thus are not directly affected by abiotic factors in the lake or pond. Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above Fish size, mobility, and sensory capabilities allow them to exploit a broad prey base, covering multiple zonation regions. Like invertebrates, fish feeding habits can be categorized into guilds. In the pelagic zone, herbivores graze on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivores include fishes that feed on zooplankton in the water column (zooplanktivores), insects at the water's surface, on benthic structures, or in the sediment (insectivores), and those that feed on other fish (piscivores). Fish that consume detritus and gain energy by processing its organic material are called detritivores. Omnivores ingest a wide variety of prey, encompassing floral, faunal, and detrital material. Finally, members of the parasitic guild acquire nutrition from a host species, usually another fish or large vertebrate (Le *et al*., 2006). Fish taxa are flexible in their feeding roles, varying their diets with environmental conditions and prey availability. Many species also undergo a diet shift as they develop. Therefore, it is likely that any single fish occupies multiple feeding guilds within its lifetime (Lytle *et al*., 1999).

Lotic communities: Lotic systems typically connect to each other, forming a path to the ocean (spring → stream → river → Ocean). Up to 90% of invertebrates in some lotic systems are insects. These species exhibit tremendous diversity and can be found occupying almost every available habitat, including the surfaces of stones, deep below the substratum, and in the surface film. Invertebrates are important as both consumers and prey items in lotic systems. Insects have developed several strategies for living in the diverse flows of lotic systems. Some avoid high current areas, inhabiting the substratum or the sheltered side of rock (Le *et. al*., 2006). In addition to these behaviors and body shapes, insects have different life history adaptations to cope with the naturally-occurring physical harshness of stream environments (Lytle *et al*., 2004). The common orders of insects that are found in river ecosystems include Ephemeroptera (also known as a mayfly), Trichoptera (also known as a caddisfly), Plecoptera (also known as a stonefly, Diptera (also known as a true fly), some types of Coleoptera (also known as a beetle), Odonata (the group that includes the dragonfly and the damselfly), and some types of Hemiptera (also known as true bugs). Additional invertebrate taxa common to flowing waters include mollusks such as snails, limpets, clams, mussels, as well as crustaceans like crayfish, amphipoda and crabs. Fish are probably the best-known inhabitants of lotic systems. The ability of a fish species to live in flowing waters depends upon the speed at which it can swim and the duration that its speed can be maintained. Continuous swimming expends a tremendous amount of energy and, therefore, fishes spend only short periods in full current. Instead, individuals remain close to the bottom or the banks, behind obstacles, and sheltered from the current, swimming in the current only to feed or change locations. Some species have adapted to living only on the system bottom, never venturing into the open water flow. These fishes are dorso-ventrally flattened to reduce flow resistance and often have eyes on top of their heads to observe what is happening above them. Some also have sensory barrels positioned under the head to assist in the testing of substratum. Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species, and mammals (e.g., otters, beavers, hippos, and river dolphins). Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (snakes, turtles, crocodiles and alligators) various bird species, and mammals (otters, beavers, hippos, and river dolphins). With the exception of a few species, these vertebrates are not tied to water as fishes are, and spend part of their time in terrestrial habitats (Giller *et al.*, 2000). Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Fish fauna: Ganga water fish fauna consisted 25 fish families and 149 fish species along the study 58 species are present in mountain region and 122 (Hardwar to Bijnor) species in plane region. Maximum fish species are common to Mountain Region and Upper Gangetic Plane. In present study past, 21 fish species (Carp: Catfish: Other = 18:2:1) were observed from Devprayag to Rishikesh zone, 22 fish species (Carp: Catfish: Other = 13:6:3) at Narora and 27 species at Kachla Ghat (Carp: Catfish: Other = 8:7:14) and 31 fish species at Bithoor (Carp: Catfish: Other = 12:07:12). Earlier, 30 fish species (Carp: Catfish: Other = 20:3:7) were recorded in Rishikesh-Hardwar zone (Giller *et al.*, 1998), 6 fish species (Carp: Catfish: Other = 14:4:9) around the Bijnor District (Khanna *et al.*, 1994). In Lower zone of the Ganga the 82 fish species (Carp: Catfish: Other = 45:17:20) have been reported between Brijghat to Narora (Sharma *et al.*, 1986; Rao *et al.*, 2001). A recent information shows 58 fish species (Carp: Catfish: Other = 26:18:14) at Narora (EEF-India, 2004). Fish population richness is evident from Mountain Zone to Upper Gangetic Plane. Stretch of the river from Hardwar to Bijnore (77 km. apart) is of special interest from the viewpoint of fish distribution since it is the junction of two biogeographic regions, the west Himalaya and the Upper Gangetic Plains. 68 species are listed in this zone of which 17 species are common with the Upper Mountain Zone (above Devprayag), 37 species (including 17 from Upper Mountain Zone), that are present in Lower Mountain Zone (Devprayag to Hardwar), 9 species are specific to this junction and 21 species are common to Upper Gangetic Plane. Thus, this zone has a larger share of mountain and Plane. It is notable that some essentially coldwater species i.e. snow trout, *Garra* and *Glyptothorax* extend their range into the Upper Gangetic Plane but are few in junction zone. Distribution and diversity of 149 fish species belongs to 25 families in the mountain (M) and the upper Gangetic plains was studied (Nautiyal *et al.*, 2014).

Aquatic ecosystems are critical components of nature. In addition to contributor of biodiversity and ecological productivity, they also provide a variety of services to human population as drinking water, irrigation, recreation, and habitat to aquatic fauna. Increase temperature is changing the distribution, migration and breeding of aquatic species. Change in seasonal patterns, precipitation, and run off affects species composition and ecosystem productivity. Wetlands ecosystems have limited ability to adapt to climate change (Day *et al.*, 2002). The effect of increased pollution and temperature adversely affects the physical, chemical and biological characteristics of water and affect ecosystem structure and function. It results into loss of aquatic biodiversity, fisheries, phytoplanktons, zooplanktons. A two-degree increase is associated with 500 ppm of CO_2 concentration changes the flora and fauna of wetlands. These impacts will add to the stress already given by anthropogenic activity. A climate change brought about by human activities is threatening to accelerate the loss biodiversity. Climatic changes and anthropogenic activities play a dominant role in maintaining the fish population and diversity (Anttrill and Power, 2002). Surface freshwater is a small fraction of global water. It may cause extinction of aquatic mammals and reptiles at species level which are restricted in their geographical ecology. Biodiversity is very sensitive to even small change in the Earth's climate. There is a need for conservation of diversity through planning and management. Urgent steps and efforts are required to mitigate the losses in biodiversity and implement the long-term measures to preserve the rich treasures of Haidarpur wetland of Bijnor. Biodiversity conversation cannot be brought about by enforcement of laws only, it must come from within because we should love the nature and all living being. Biodiversity is life. It is the nature's insurance policy against disasters (IPCC, 2014).

Conclusion and future recommendation

Healthy freshwater ecosystem provides vital ecosystem services to human societies including the provision of clean water for drinking, agriculture, fisheries, flora, fauna, wetlands and biodiversity. The present reports hydrobiology characteristics of Ganga river barrage at Bijnor Uttar Pradesh. Water samples were monitored for 5 standards Aldrin group, hexachlorocyclohexanes (HCHs), DDTs and OCPs. The outcomes analyze the pH of water, Total Dissolve Solids (TDS) values extending from 115 to 676 mg/L, averaging 271 mg/L. Cations concentration $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and anion concentration (mg/L) were $HCO_3^- > SO_4^{2-} > Cl^- > CO_3^{2-}$. Maximum hydro chemicals were in the form of bicarbonates Ca–HCO_3 type. The hydrochemical characterization evaluates the quality of water for irrigation purpose. Water quality analysis shows variations at different sites and seasons thus affecting the habitat, growth, reproduction and migration of aquatic flora and fauna. The quality of water is suitable at a particular season for bathing and irrigation purposes at Ganga Barrage, Bijnor Uttar Pradesh. The hydrochemical characterization was different from upper and downstream of the main stream. Bijnor Ganga Barrage fauna is facing the threats of broad categories like variation in nutrient enrichment, hydrological modifications, chemo geodiversity, habitat loss, degradation, and pollution, dominancy of invasive species, extreme flood and draught. To improve the quality of Ganga water we should farmers should reduce the use of insecticides, pesticides and herbicides in agriculture.

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Chapter [23]

Geo-environmental assessment in semiarid region of Pulivendula tehsil, Kadapa district, Andhra Pradesh, India

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Abstract

We aim to integrate geo-environmental datasets in drought afflicted Pulivendula tehsil, Kadapa district for preserving agro-ecosystems with erratic seasonal rains and rapid degradation of natural resource base. An agroecosystem model was devised based on three key inputs which were characterized with agroclimatic data, geopedological data from semi-detailed survey, and a delineation of potential areas for groundnut and banana under drip irrigation. Results of 21 years of rainfall analysis indicate that the region receives 650mm of rainfall, providing a productivity of 660kg/ha for groundnut and less than 300kg/ha for red gram, with measurable decreases in area. We derived four clusters and estimated that 35 percent of the area is at high to extremely high risk of soil erosion with poor soil quality (mean of 22.83%) and significant differences between the groups. Nearly 35K hectares are suitable for banana under drip irrigation and fifty-six thousand hectares are suitable for groundnut cultivation with limitations on rooting depth, topography, coarse fragments, alkalinity, and soil organic matter. Using time series data on crop acreage, productivity, and rainfall in conjunction with geo-environmental data sets under GIS in order to identify ecological health indicators.

Keywords Agricultural landscapes, Cuddapah basin, Drought prone, Land Resource

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Introduction

There are 40 percent of land areas at global scale in the arid and semiarid regions, whose environmental problems include the loss of ground water and bio diversity and affecting livelihood of rural communities (Chuvieco *et al*., 2014; Beroya-Eitner, 2016, Peng *et al*., 2019). In the twentieth century, we observed rising temperatures and significant changes in climate and environment. We also witnessed ecosystem changes, such as loss of biodiversity, frequent occurrences of extreme weather events, and increasing desertification in semiarid regions (Farley and Voinov, 2016; Heltberg *et al*., 2009). Analysis of the regional agroecosystems for the conservation of natural resources and to predict the impact of unexpected weather changes under different land use scenarios were reported (Foley *et al*., 2005; Sun *et al*., 2018; Wu *et al*., 2018). The systematic research methodologies were applied in order to understand the natural relationship of landuse change and agro ecosystems in semiarid regions (Arowolo *et al*., 2018; Mouchet *et al*., 2017). Most of the studies were made and interpreted landuse change in terms of economic value (Zhou *et al*., 2018) but Allan *et al.* (2015) evaluated the biodiversity, functional traits in 14 ecosystems in 150 plots of grasslands under the different landuse intensities. Now the current research trends showed that ecosystem services are linked with land use with natural (Kong *et al*., 2018) and humanistic features of landscape (Said and Spray, 2018). The linking biophysical methods with ecosystem did not provide enough information for decision makers to incorporate into the appropriate policy decisions (Gong *et al*., 2017; Zhou *et al*., 2018). During recent decades, various agro ecological frameworks have been proposed, such as the vulnerability scoping diagram (Polsky *et al*., 2007), the environmental sensitivity index (Amiri *et al*., 2014; Kang *et al*., 2018), and the pressure-state-response assessment framework (Zhang *et al*., 2017). In addition to these frameworks, and sensitivity index approaches, the statistical methods such as the principal component analysis (Li *et al*., 2006), the analytic hierarchy process (AHP) method (Topuz and van Gestel, 2016), the fuzzy comprehensive evaluation method (Adriaenssens *et al*., 2004) and the entropy methods were used (Amiri *et al*., 2014; Hou *et al*., 2015).

The rain fed agriculture in India is in 66% of total cropped area (Planning Commission, 2012) and occupy second largest producer of rice and wheat under rain fed (FAO, 2018). It was reported that there are drastic climatic changes, perceptibly rise in surface temperature of about 0.4°C, and decreasing monsoon rainfall of 6–8% over north eastern India, Gujarat, and Kerala (Government of India, 2008). Climate change of arid and semiarid regions in future will serve as a mark of food starvation risk affecting negatively on food security and rural livelihoods (Krishnamurthy *et al*., 2012). Indicator methods were used to quantify vulnerability to climate change (Chaliha *et al*., 2012; Piya *et al*., 2012) but limited studies focused on vulnerability of small farm holders among rain fed farmer's (Harvey *et al*., 2014; Gopinath and Bhatt, 2012; Mongi *et al*., 2010). Several studies related to agricultural drought in India were reported for *kharif* season (June–September) (Nataraja and Ram Mohan, 2010; Murthy *et al*., 2011). The agricultural droughts were quantified using both meteorological and satellite-derived indices, such as normalized difference vegetation index (NDVI Dev), vegetation condition index (VCI) and standardized precipitation index (SPI) (Dutta *et al*., 2015; Bhavani *et al*., 2017). In India, the vulnerability of agro ecological systems of 597 districts were carried out for assessing climatic variability, ecological and demographic sensitivity and socio-economic capacity. The results showed that Western plains, Northern plains, and Central highlands of the arid and semi-arid agro-ecological zones represent vulnerable regions of the country (1950–2000). The futuristic scenario (2050), clearly shows that Deccan plateau and Central (Malwa) highlands, lying in the arid and semi-arid zones are extremely vulnerable (Shukla *et al*., 2017). The climatic vulnerability studies for rain fed tropics (CVI ^{RFT}) in some of the watershed studies in Kerala, showed that there is a need of reorientation of the policy with key on integration of socio-economic data sets with natural resource management.

The present study was carried out in parts of semiarid region of Pulivendula tehsil, Kadapa district, Andhra Pradesh (AP) with high degree of vulnerable to agricultural drought in the changing climate scenario. This is an ideal site to assess the degree to which natural ecosystems are pressured by deforestation and land use pressures that affect the vulnerability of agricultural systems. The potential agricultural zones for locally adopted crop production enhancing technologies will certainly influence on agrarian communities to maintain yields and conserve soil resources. The challenges of natural resource management in semi-arid regions of Rayalseema plateau with special reference to Pulivendula tehsil are off rugged and dissected terrains of different geological formations, high density of marginal farmer's and low input subsistence farming. The study was designed to integrate geoenvironmental assessment and the structure of rain fed agro ecosystem for development programs to provide strategic support to homogenous soil-crop zones. Some soil crop studies in the region were reported with respect to land evaluation for Groundnut (Rajendra Hegde *et al*., 2018) and aridity analysis (Bhaskar *et al*., 2019). Therefore, it becomes important to understand the relationship between the geo-environmental assessment, and sensitivity of agro ecosystems (distribution among three cropping seasons, the ratio of cropped area to fallow area, percent fluctuation of cropped area) in different districts. The specific objectives of the present study are to identify and describe the important components of the different geopedological systems and agro ecosystems (system definition) in defining biophysical constraints and opportunities for agro management and development options.

Description of the study area

Pulivendula in Kadapa district (14°16′to 14°44′ N and 77°56′ to 78°31′E) covers 1,46,235 ha. This tehsil has six mandals namely: Pulivendula, Vemula, Vempalli, Tondur, Simhadripuram and Lingala (Figure 1). This study area is a part of semiarid climate with mean annual rainfall of 564mm and 43 rainy days. The length of growing period (LGP) is varied from 90-105 days for Pulivendula and Vemula, 105-120 days for Lingala and Tondur and 120-135 days for Simhadripuram and Vempalli mandals. This area is moderately to marginally suitable for peanut cultivation under hot arid ecosubregion (K6E2) with deep loamy and clayey mixed red and black soils of Rayalseema plateau (Mandal *et al*., 1999). The terrain has rugged hills with valleys, severely eroded pediments and moderately to gently sloping pediplains. The study area is composed of the Papaghni and Chitravati group of rocks of Cuddapah

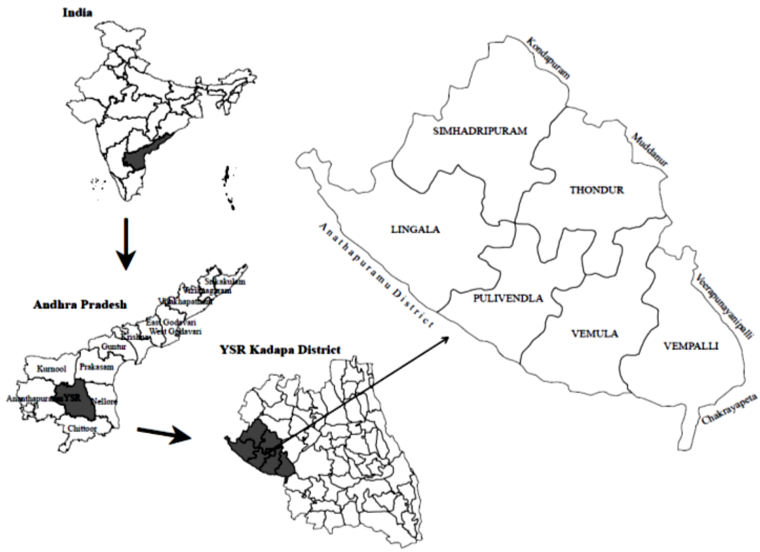

Figure 1. Location map of Pulivendula tehsil, Kadapa district, Andhra Pradesh.

Super Group. The rock types of Papaghni group consists of quartzite, arkose and conglomerates. The Chitravathi group of Vempalle formation consists of dolomites, chert, mudstone, quartzite, basic flows and intrusive rocks whereas quartzite with conglomerates of Pulivendula formation and shales, dolomite/quartzite of Tadipatri formations (Basu *et al*., 2009). Using remote sensing data of Indian Remote sensing satellite (IRS-P6-LISS-IV) data on 1:25000 scale, was used to delineate 9 broad landforms such as elongated ridges/cuseta (750-360m above mean sea level), dissected hills/summits, highly dissected plateau remnants, isolated hills/monad nocks/mounds/ tors/boulders/ domical rises/rock outcrops (54135ha of total area), interhill basins (6163ha of total area), undulating upper sectors, gently sloping middle sectors (39092ha of total area) and colluvial lower sectors (28542 ha of total area).

Agroecosystem analysis

The Agro ecosystem Analysis (AEA) was performed in three steps such as: I. agro climatic analysis (rainfall and temperature), II. geo-pedological data sets, and III. suitability of soil units for groundnut and banana under drip irrigation. The data integration of agroecosystem analysis was given in Figure 2. Agroclimatic analysis of 20 years of data regarding area and productivity of groundnut /redgram and rainfall at district level (2000-2001 to 2018-2019) was collected from internet source (https://aps.dac.gov.in). The bivariate plots were constructed and developed regression equations using Microsoft Excel 2007. The bivariate plots of rainfall versus productivity and area of groundnut and red gram were analysed. The bar diagram for south-west monsoon months were worked out.

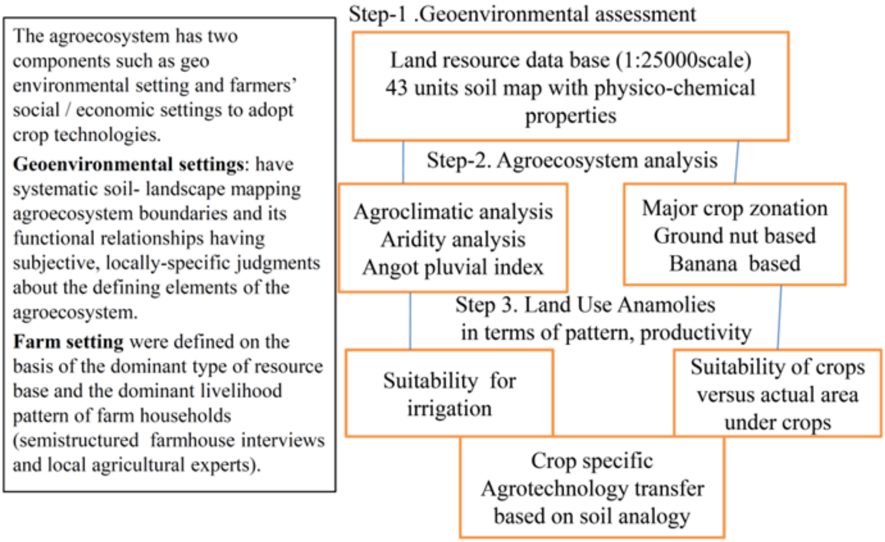

Figure 2. Relation of geopedological data with agroecosystem analysis in a part of Pulivendula.

Geoenvironmenal assessment

The semi detailed soil survey was carried out as per standard methodologies. The base was prepared using IRS-P6-LISS-IV (1:25000 scale) in conjunction with topographical and geological maps (1:50000 scale) of Pulivendula tehsil in Kadapa district (Figure 1). The semi detailed survey was carried out using geomorphological map as base for selection of transects and also random checks (Soil Survey Division Staff, 2017; Shalaby *et al*., 2017). The soil data comprises of both from field observations and laboratory data for major soil series in the region (Dent and Young, 1981; Grunwald, 2005). Sixty-six transects were selected and studied over 330 profiles (cut across as 3 to 4 landform units). 120 random checks were made to verify the occurrence of series in relation to landforms. The field work was partially confirmed with soil correlation work and their laboratory analyses. The morphological properties of twenty-five soil series were described as per Schoeneberger *et al.* (2012). The horizon wise soil samples were collected for major soil series. The samples were air-dried and passed through 2 mm sieve for fine earth fraction. The fine earth fraction was used for determination of both physical (particle size distribution) and chemical properties as per standard procedures (Dewis and Freitas, 1970). The soils were classified upto series level (Soil Survey Staff, 2014). These series are generally considered as carriers of soil information. Thereby, soil series associations were made as mapping units for soil survey interpretations. The soil map was generated in GIS environment (ARC info. Version 10). The soil survey data was compiled and published at a scale of 1:25,000 (Naidu *et al.*, 2009). The soil erosion was computed for each soil mapping unit as per USLE (Wischmeier and Smith, 1978). Based on the values, these mapping units were categorized into 8 classes as: very low = soil loss of <0.5t/ha/year, low = 0.5-

1t/ha/year, low-medium = 1-2t/ha/year; medium = 2-5t/ha/year; high-medium = 5-10t/ha/year, high = 10-20t/ha/year, very high = 20-50t/ha/year and extremely high = >50t/ha/year. The land evaluation for banana and groundnut was made as per Sys *et al*. (1993). The parametric approach of Sys *et al*. (1993) was used to evaluate each mapping unit for their suitability to drip irrigation. The soil quality assessment was made as per the rating chart of Idowu *et al*. (2009). The scheme of rating chart for 11 soil variables was given in Table 1.

Table 1. Rating chart for soil quality index.

Soil variable	**Values/rating**					**Maximum value**
Soil CEC/group	<4.6(1)	4.7-9.0/2	9-15/3	>15/4		
	2	4	5	5		5
Soil pH	<5	5.1-5.8	5.9-7.0	7.1-8.0	>8	
	0	10	15	10	5	15
P rating	low	Medium	high	Very high	Extremely high	
	0	5	10	5	0	10
K rating	low	Medium	high	Very high	Extremely high	
	0	5	10	8	5	10
Base saturation (%)	<10	11-25	26-50	51-75	>75	
	0	3	6	10	8	10
Soil organic matter(%)	<1	1.1-2.0	2.1-3.0	3.1-4.0	>4.0	
	0	4	12	16	20	20
N mineralized (kg/ha)	<11	12-22	23-45	46-89	>89	
	0	1	2	3	5	5
Soil respiration	Very low	low	moderate	high	Very high	
	0	1	2	3	5	5
Aggregate stability	No aggregates	weak	Moderate	Good	Very strong	
	0	2	4	6	8	8
EC(dSm^{-1}) 1:2soil water ratio)	<0.20	0.21.- 0.4	0.41-0.80	0.81-1.6	>1.6	
	3	5	3	2	0	5
Metals	Two or more metals "very high"		One metal is very high		All metals are optimum	
	-10		-5.0		7	7
			Total			100

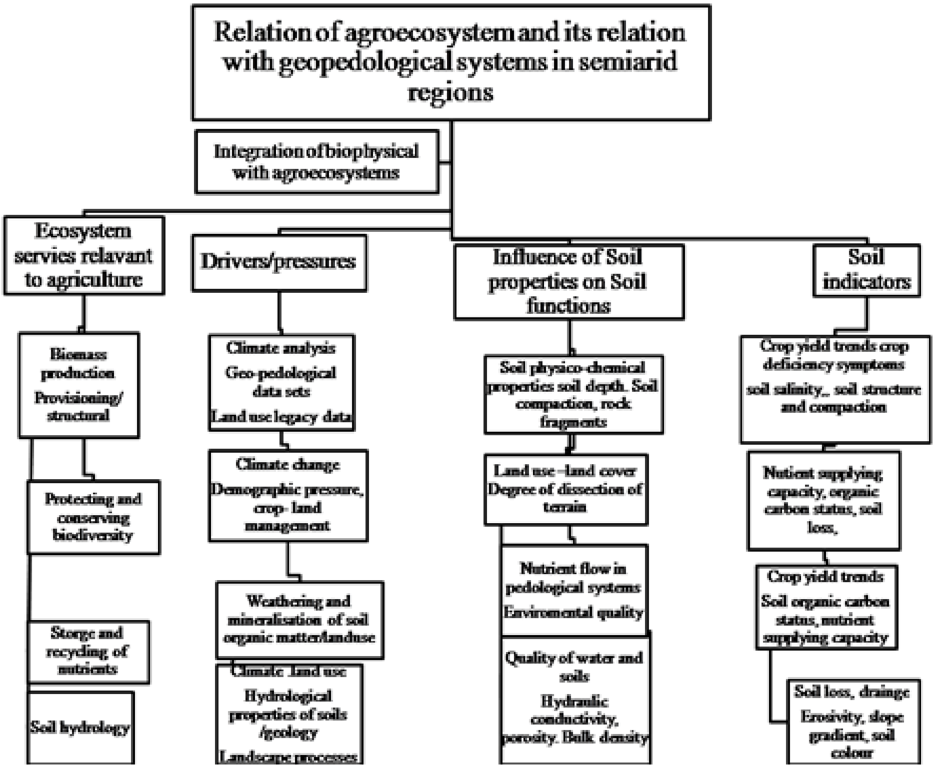

Figure 3. Relation of geopedological data with agroecosystem analysis in a part of Pulivendula.

Land use anomalies in terms of area and productivity

The geopedological data was integrated with existing agro ecosystems of Pulivendula tehsil, Kadapa district to know the anamolies in terms of land use. The framework was designed to address two key aspects of pedological systems such as soil capability (determined by the inherent, largely stable properties) that determine the natural limitations for crop productivity, (FAO, 1976, 2007; Dominati *et al*., 2010) and soil condition (determined by variables that reflect the soil status, and thus the current productivity). These two aspects (soil capability & resilience) of geopedological data was used to assess the land potential and their susceptibility to degradation or change in the context of geomorphic setting (Oeh, 2012; Gray *et al*., 2015; Orr *et al*., 2017). The land suitability (FAO, 1976, 2007) was made to delineate suitable areas for specific and for monitoring soil condition under a defined set of land management practices of local importance. This scheme was partly adapted from the works of Lal (2016); Hazelton and Murphy (2016); Sangeda *et al*. (2014) but slightly modified to fit in the present study (Figure 3).

Table 2. Statistical summary of year wise and seasonwise area and productivity of redgram and groundnut in Kadapa district (Source: https://aps.dac.gov.in)

Year	Red gram					Groundnut				
	Area(ha)			Productivity (t/ ha)		Area(ha)			Productivity (t/ ha)	
	kharif	rabi	Total	kha-rif	rabi	kharif	rabi	Total	kha-rif	rabi
2000-2001	15189	168	15347	0.55	0.55	150521	26324	176845	1.16	1.24
2001-2002	12059	67	12126	0.59	0.6	119708	20282	139990	0.36	1.72
2002-2003	15983	36	16019	0.16	0.17	87896	18282	106178	0.13	1.35
2003-2004	29594	75	29669	0.3	0.31	109650	19746	129396	0.2	1.69
2004-2005	18424	44	18424	0.26	0.25	201338	17604	218942	0.54	2.58
2005-2006	16390	0	16390	0.27	0	184333	22988	207321	0.09	1.84
2006-2007	9313	6	9319	0.16	0.17	46532	16080	62612	0.27	2.06
2007-2008	14000	0	14000	0.29	0	145000	28000	173000	1.9	1.25
2008-2009	10488	0	10488	0.08	0	124382	16630	141012	0.23	2.16
2009-2010	12353	171	12524	0.17	0.17	111105	19013	130118	0.32	3.15
2010-2011	19759	23	19782	0.29	0.3	143299	17296	160595	0.61	2.99
2011-2012	8998	81	9079	0.25	0.25	36869	20188	57057	0.33	2.39
2012-2013	10000	0	10000	0.1	0	44000	21000	65000	0.25	1.52
2013-2014	8085	31	8116	0.3	0.29	42251	17263	59514	1.02	2.16
2014-2015	2367	24	2391	0.15	0.17	15754	11588	27342	0.44	1.33
2015-2016	7709	54	7763	0.4	0.41	28676	21983	50659	1.28	2.16
2016-2017	17885	32	17917	0.2	0.19	52015	13396	65411	0.38	3.43
2017-2018	8848	110	8958	0.3	0.3	25317	19056	44373	1.56	1.69
2018-2019	4178	121	4299	0.14	0.14	8627	11113	19740	0.52	0.97
2019-2020	4187	186	4373	0.35	0.35	8332	13495	21827	1.58	2.94
mean	12290.4	61.4	12349	0.26	0.231	84280.2	18566.3	102846.	0.66	2.03
sd	6385.07	60.3	6372.7	0.13	0.178	60857.5	4381.04	63313.2	0.55	0.70
CV	51.95	98.2	51.60	50.61	73.14	72.20	23.59	61.56	83.60	34.59
skewness	0.85	0.93	0.86	1.02	0.49	0.40	0.28	0.36	1.07	0.49
kutosis	1.46	-0.24	1.50	1.05	0.16	-1.10	0.18	-1.16	-0.12	-0.68

Agroecosystem analysis

The agroecosystem analysis in Pulivendula tehsil is evaluated in terms of sustainability of groundnut (area and productivity trends)/red gram production systems. To justify the question of sustainability of agroecosystems, the time series data analysis is considered and discussed as below.

Sustainability of groundnut/red gram in Kadapa district

The data over 20 years (200-2001 to 2018-2019) on area and productivity of two principal crops, namely red gram and groundnut, is presented in Table 2. The data showed that the mean area under red gram is 12290.45±6385.07 ha during *kharif* and 61.45±60.36 ha during *rabi*. The coefficient of variation for area under *kharif* is 51.95 % with mean productivity of 0.26±0.13 t/ha and yield variation of 50.61 per cent.

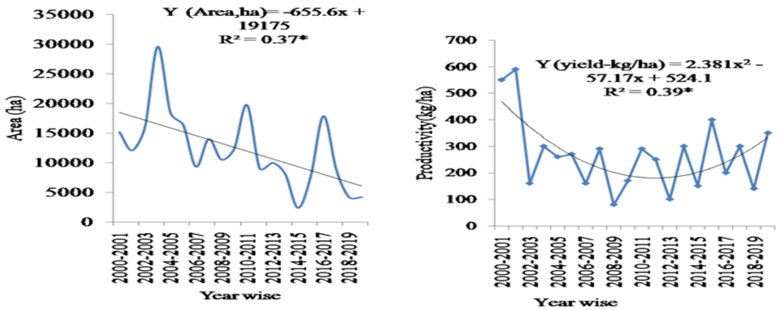

Figure 4. Area and Productivity of red gram during kharif (2000-01 to 2018-2019).

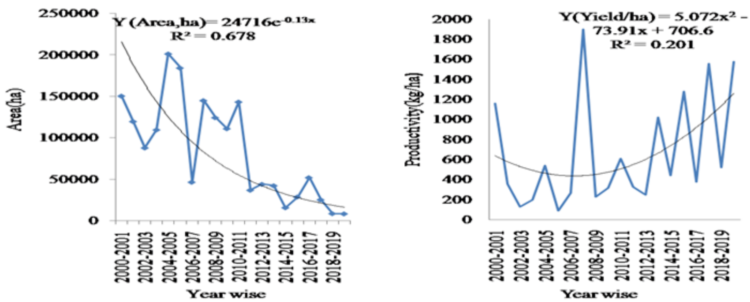

Figure 5. Yearwise area and productivity of Groundnut (2000-2001 to 2018-2019).

The productivity of red gram in *kharif* season in Kadapa is almost less than half to that of national average productivity (885 kg/ha). The mean area under *kharif* groundnut is 84280.25±60857.76 ha with variation of 72.20 per cent but the area under rabi is 18566.35±4381.04 ha with variation of 23.59 per cent. The mean productivity of *kharif* groundnut is 660±550kg/ha with variation of 83.60 per cent (national average yield of 1424 kg/ha (Directorate of Economics and Statistics, 2017). The productivity of *rabi* groundnut is 2.03 ±0.7 t/ha which is three times more to that of *kharif* groundnut. The skewness of area and productivity is less than +1 for red gram indicating substantially skewed but values less than 0.5 as noticed for groundnut indicating moderately skewed. The kurtosis is less than three indicating platykurtic with shorter and thinner tails (Hair *et al.*, 2017). The graphs of area and productivity of *kharif* red gram shows that There is drastic decrease of area from 229954 ha during 2003-2004 to 4187 ha during 20019-2020 (Figure 4). The bivariate plot of area over years has yielded a linear regression equation with R^2 (coefficient of determination) of 0.37* (p=0.05). The productivity graph over years has yielded a polynomial equation with R^2 of 0.39* (p=0.05). Similar kind of graphs are constructed for groundnut where there is a significant reduction in area over a period of 20 years and yielded an exponential equation with R^2 value of 0.678**(p=0.01). The peak-sown area under groundnut is recorded during 2004-2005 covering 201338 ha but drastically decreased to less than 10000 ha during 2018 to 2020 (Figure 5). This data analysis undoubtedly raises the question of sustainability of groundnut production as there is a sudden drop in both area and productivity.

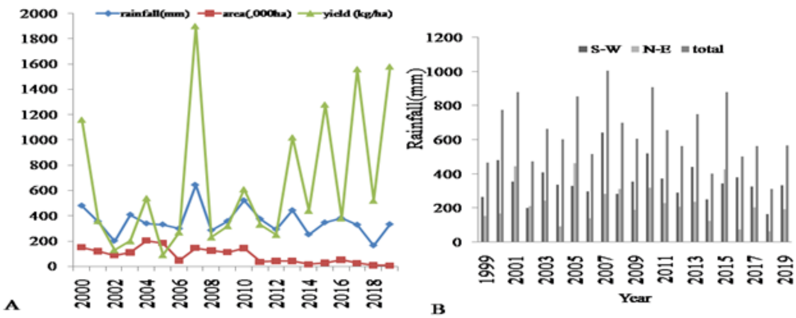

Figure 6. Relation of (A)south-west rainfall (mm) with area and productivity of groundnut and contribution of S-W and N-E to total rainfall in Kadapa district.

Relation of groundnut yield with rainfall

The drought hit Pulivendula is really challenge to both crop planners and resource managers regarding the trends of groundnut shift and then to go for alternatives. Looking into the crisis of groundnut under rain fed, the rainfall analysis with main focus on seasonal dry spells during *kharif* is made in relation to productivity. The main focus is given for groundnut considering its area during *kharif*. Parmar (2013) reported a positive relation between amount of rainfall and yield of groundnut and expressed its relation in an equation as : Yield =15.01 + 1.892 June + 2.301 July +1.582 August + 0.648 September with R^2 (coefficient of determination) of 0.48.

The mean rainfall of the region is 650.6 mm ± 183.8 mm and coefficient of variation of 28.2%. There are only two seasons viz., South-West (S-W, June to September) and Northeast (N-E) monsoon. The S-W monsoon receives mean rainfall of 352.4 ± 107.8 mm and shares 54.2 % of total rainfall. The mean N-E monsoon receives 228.6 ±114.2mm but shares 35.1 % of total rainfall. The bivariate plot between rainfall and area under *kharif* groundnut has yielded power relation as Area (ha) = 8.03 *(rainfall, mm) $^{1.53}$ with a coefficient of determination (R^2) of 0.303*(significant at 5% level). The effect of rainfall on yield of groundnut has 3rd order poly nominal equation (R^2 = 0.363) significant at 5% level. These relations are depicted in Figure 6(A) and the contribution of S-W and N-E monsoon rains to total in Figure 6(B). The setting criteria for good groundnut harvest is to have minimum monthly rainfall of 100 mm and temperature of 21 °C over the entire growing period (Cox, 1979, Varaprasad *et al*., 2000). The monthly decadal data of study area has De Martonne Aridity Index (I_{dm}) below 15 to define climate as semiarid and needs irrigation in times of drought (Zambakas, 1992, Bhaskar *et al*., 2019). Under this type climatic conditions, Radha kumara *et al*. (2016) advocated to identify alternate remunerative crops to rain fed groundnut in Alfisols and able to produce about 5 to 10 kg/ha of pods per millimeter of rainfall. For dry land peanuts, in the region an average rainfall of at least 400 mm from June to September is needed to produce a reliable crop. The long-term rainfall data shows a deficit of 60 mm during pod development phase (September, Bhaskar *et al*., 2019). Hence, the region experiences serious yield loss and reportedly low averge yields of groundnut. Thereby, the area under groundnut is drastically dropped to below 10000ha during 2018-2019.

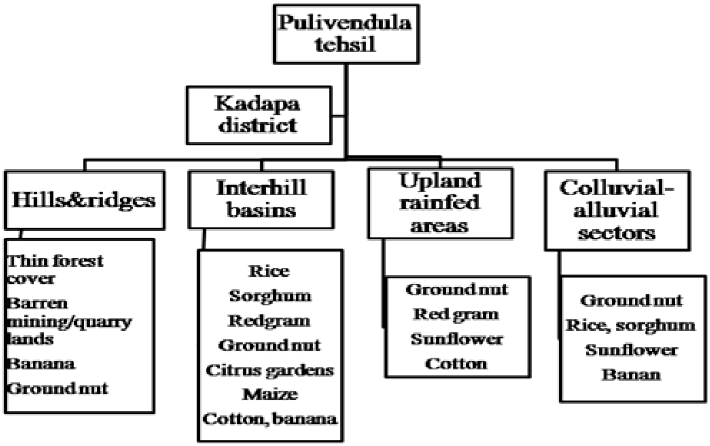

Figure 7. Agroecosystem hierarchy levels in Pulivendula tehsil, Kadapa district.

Geoenvironmental assessment

The geoenvironmental assessment is prerequisite for restructuring semiarid agro ecosystems experiencing serious economic losses. The two ways of geopedological analysis in relation to agro ecosystems on land use decisions depends on the geopedological knowledge used to understand the kind of ecological functions and services to the locals under a define sets of social-cultural context and application of soil-landscape knowledge for scientific transferring of agro technology.

At first, the subject of agro ecosytem deals with hierarchy of agri resource information in defining ecosystems of a region (Figure 7). Broadly, the Pulivendula tehsil has four distinct ecosystems such as hills/ridges, interhill basins, upland upper sectors and colluvio-alluvial sectors. The visual interpretation of IRS-P6-LISS-IV data on 1:25000 scale, revealed 4 broad landforms. The data shows that hills/ridges cover 54135 ha of total area followed by undulating upper sectors (39092 ha), colluvial lower sectors (28542 ha) and interhill basins (6163 ha). Among four landforms, 32.8 percent of area is under hills and ridges whereas 36.82 per cent of area is under undulating upper sectors used for groundnut based cropping systems. The groundnut grown in shallow stony red soils of hills and ridges and undulating upper sectors experiences severe water stress and incur serious crop loss during drought periods. The colluvial-alluvial sectors (22 per cent of area) and interhill basins (4.68%) are extensively used for banana and citrus cultivation. The cropping systems mentioned in flow chart (Figure 7) are commonly grown under different landscapes of varied geological formations in the region. The results on mixed cropping sorghum/pigeon pea/groundnut/cotton/bengal gram are more economically enumerative as against low productive monoculture of groundnut (Bhaskar *et al.*, 2019). The field photo’s of agricultural landscapes at study site showed that hills are open and fully exposed to different degrees of erosion. The hills are mostly covered with stony surface cover (Figure 8). The field photos shows that locals are not paying due attention on conserving and protecting the biodiversity in geological landscapes. Now-a-days, the upland sectors in western parts of tehsil are intensively used for commercial production of banana under drip system but the ploughed for

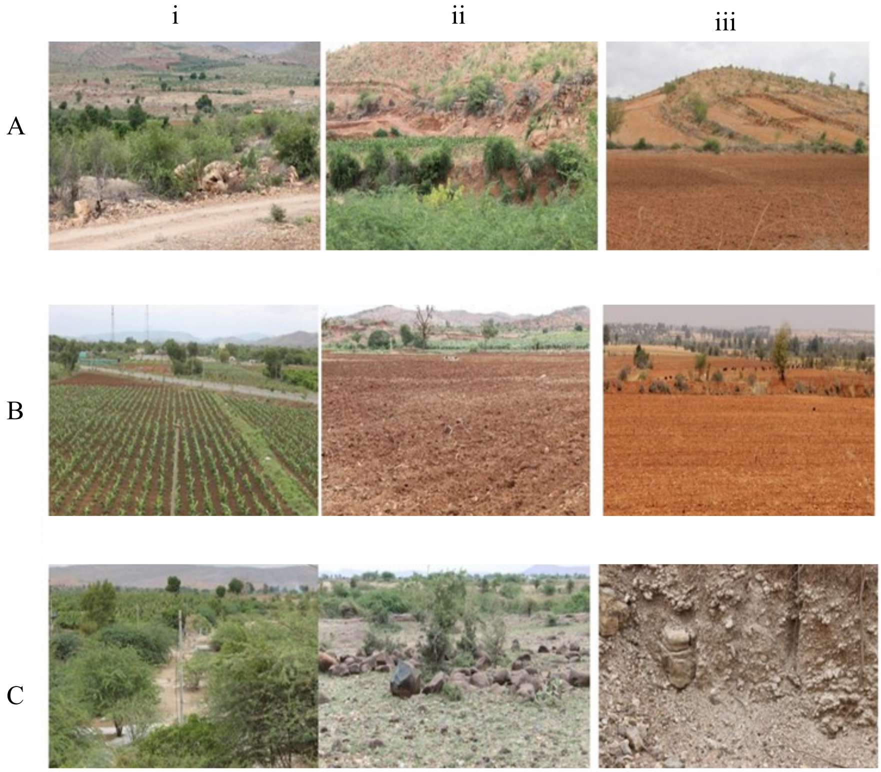

Figure 8. View of landforms (A).hills and ridges –i.dolomitic hills with thin vegetation cover , ii.quartzitic hills with thin forest cover and gravelly surface and iii. Hills with rock bunding made for banana cultivation (B). undulating upper sectors –i. banana field under drip system of irrigation , ii. Prepared for sowing groundnut and iii. dry fields during summer, (C) colluvio-alluviall sectors- i.badly managed stream floors , ii. Severely dissected rocky surfaces and iii. Cut off and exposed river banks enriched with lime content.

groundnut in red soils during *kharif*. The neglected parts of colluvio-alluvial sectors are heavily infested with *Prosopis* and have surface salt encrustations and calcium carbonate concretions in subsoil's. The agricultural land use is mostly groundnut as major but, banana and rice is grown under irrigation in interhill/colluvio-alluvial sectors (Figure 9). The field evidences strongly advocate adopting agro ecology principles in the region with a view to optimizing nutrient cycling, productivity of crops over time (Conway, 1985) and enhancing soil biological activity at landscape level (Altieri *et al*., 2015). This region is technically defined as "production syndrome" with a defined set of management practices (Andow and Hidaka, 1989) that are mutually less adaptive and not explained by the additive effects of individual practices.

Figure 9. Monoculture of land use systems in Pulivendula tehsil.

Textural and chemical characteristics of soil series

The soils on quartzitic landforms have mean pH of (P1 to P5) 7.68 ± 0.68 with coefficient of variation of 7.99 per cent but, soils on shale's have mean of 8.01 ± 0.2 with coefficient of variation of 2.47 (Table 3). It had been reported that the slightly alkaline upland soils with a pH up to 8.0 in Pulivendula are evaluated as suitable for groundnut (Vara Prasad *et al.*, 2000). The Pulivendula series (P21) has low organic carbon of 2.6gkg^{-1} but more than 10gkg^{-1}in case of P8, P13, and P19 with mean of 7.26 ± 3.13 gkg^{-1}. The mean organic carbon in quartzitic soils is 13.58 ± 4.24 gkg^{-1}. These soils have medium to high status of organic carbon and can be used for sustainable groundnut production (Hazelton and Murphy, 2007). Four groups of soils are identified based on CEC. Seventy two per cent of soils per cent of soils have high (48%) to very high CEC (24%). The remaining 28 % soils are grouped under low (12%) to moderate CEC (16%). These soils have calcium carbonate ($CaCO_3$) content of 10 g/kg in P1 to 160 g kg^{-1} in P12. The appearance of calcic layer in support $CaCO_3$ content is used to classify Vemula series (P12) under the subgroup of Calcic Haplustalfs. The calcium carbonate content is generally low in quartzitic soils (mean of 20 ± 10 gkg^{-1}) but relatively more in soils on shale (mean of 87.62 ± 46.57 g/kg). It is observed during soil surveys that the soils of interhill basin and colluvial alluvial complex have higher

Table 3. Physical and chemical characteristics of soil series in Pulivendula tehsil.

Soil series	Particle size distribution (%)			Textural class	pH	EC (dSm^{-1})	Organic carbon	$CaCO_3$	CEC cmol /kg	PBS	ESP	Depth (cm)	Erodibility index (K)
	Sand	silt	clay				g/kg						
1. Kanampalli(Kpl)	72.1	4.3	23.6	scl	8.3	0.14	16.3	10	12.9	71	0.16	21	0.16
2. Ganganapalle (Ggp)	32.1	20.5	47.4	c	7.1	0.23	17.7	30	30.5	100	0.39	15	0.19
3. Lingala(Lgl)	44.4	23.8	31.8	gcl	8.1	0.22	11.9	20	26.6	100	0.15	47	0.28
4. Rachakuntapalle (Rkp)	57.3	18.3	24.4	gscl	7.2	0.16	8.4	1.0	25.7	46	0.16	40	0.27
5. Mupendranapalle (Mpl)	29.5	29.0	41.5	c	8.4	0.38	10.7	40	29.1	100	0.76	40	0.23
6. Tallapalle(TlP)	40.9	19.6	39.5	cl	7.9	0.19	9.7	70	28.3	100	1.13	40	0.25
7. Santhakovur(Skv)	48.8	18.7	32.5	gcl	7.9	0.29	9.2	150	21.7	100	2.76	62	0.33
8. Tatireddipalle(Trp)	14.9	27.8	57.3	c	7.7	0.22	11.2	40	54.5	100	0.26	55	0.16
9. Cherlapalle(Cpl)	32.5	21.2	46.3	c	8.1	0.34	6.2	110	33.2	100	23.6	105	0.17
10. Kottalu(Ktl)	74.9	10.3	14.8	sl	7.9	0.16	3.6	20	7.6	100	1.97	142	0.21
11. Murarichintala (Mct)	71.1	14.2	14.7	sl	8.0	0.25	4.7	10	7.2	100	0.14	155	0.27
12. Vemula(Vml)	32.8	24.9	42.3	c	8.0	0.20	7.0	160	30.1	100	1.79	72	0.22
13. Sunkesula(Skl)	50.1	15.4	34.5	scl	8.0	0.30	11.1	40	28.0	100	1.61	70	0.18
14. Simhadripuram (Spm)	23.2	21.5	55.3	c	8.0	0.25	8.4	140	42.7	100	6.46	92	0.15
15. Velpula(Vpl)	60.7	13.5	25.8	scl	7.9	0.14	3.3	50	13.0	100	2.31	138	0.25
16. Agraharam(Ahm)	23.6	18.2	58.2	c	8.3	0.21	9.3	110	44.2	100	2.22	120	0.10
17. Balapanur(Bpr)	23.0	24.0	53.0	c	8.0	0.41	5.7	100	37.4	100	11.0	14	0.16
18. Parnapalle(Prp)	78.4	8.9	12.7	sl	7.8	0.31	5.0	20	10.3	100	4.95	150	0.26
19. Gondipalle(Gpl)	29.5	19.4	51.1	gc	7.9	0.21	14.7	150	35.8	100	0.87	44	0.16
20. Goturu(Gtr)	42.0	13.9	40.0	c	8.2	0.47	8.4	90	36.9	100	15.7	70	0.19
21. Pulivendula(Pvd)	38.6	1.2	60.2	c	8.5	1.47	2.6	110	24.2	100	67.8	135	0.10
22. Pernapadu(Ppd)	33.4	19.3	47.3	c	8.0	0.19	6.3	130	45.0	100	0.33	103	0.24
23. Agadur(Agd)	32.6	19.8	47.6	c	7.8	0.19	5.4	100	42.6	100	0.45	145	0.13
24. Tondur(Tdr)	29.8	22.3	47.9	c	8.1	0.25	5.8	100	41.9	100	4.6	152	0.14
25. Bhadrampalle(Bpl)	45.0	5.9	49.1	sc	7.9	0.33	4.1	100	27.3	100	8.78	150	0.14

$CaCO_3$ contents due to restricted internal drainage and high degree of aridity. This observation is in agreement with reports of Bhaskar *et al*. (2015). The per cent base saturation is more than 100 per cent. Generally these soils have less than 15 per cent of exchangeable sodium per cent except P9, P20 and P21. The Cherlapalle (P9), Gottur (P20) and Pulivendula series (P21) are classified under the subgroups of Sodic Ustic Haplocambids considering the ESP more than 15% in subsoils. The erodibility index (K) less than 0.2 indicates no susceptibility to water erosion. The 14 series comes under this category viz., Kanampalli(Kpl), Ganganapalle(Ggp), Tatireddipalle(Trp), Cherlapalle(Cpl), Sunkesula(Skl), Simhadripuram(Spm), Agraharam(Ahm), Balapanur(Bpr), Gondipalle(Gpl), 20.Goturu(Gtr), Pulivendula (Pvd), Agadur(Agd), Tondur(Tdr) and Bhadrampalle(Bpl). The remaining 11 series have K values of 0.2 to 0.3 indicating weakly susceptible to water erosion (Vopravil *et al*., 2007).

Among soil properties, the soil organic carbon shows significant variation between the landforms with F value of 5.08 (p=0.008). The results of turkey test further show that there is an absolute mean difference of 7.142 with marginal error of 5 at 95 % turkey interval. The comparative mean between colluvio-alluvial sector to that of hills/ridges shows significant variation with mean of 0.0943 ± 0.0874. Similar sort of exercise performed for soil depth that shows significant variation between landforms with F value of 7.95 (p=0.001). The turkey results show that there is a significant mean difference of 60.85 ± 53.4 cm between interhill basins and hills/ridges. Like wise, there is a significant mean difference 99.14 ± 58.54 cm between colluvio-alluvial sectors and hills/ridges.

Soil mapping

Twenty five soil series are identified after field correlation and designed 43 mapping units as series association (Figure 10). Among 43 soil mapping units, eight mapping units are associated with hills/ ridges having rock outcrops and shale rock type. The sandy loam to clay loam soils in these units are very shallow, somewhat excessively drained and moderately alkaline. The eight soil mapping units cover 54812 ha (42.62% of total area, Table 4).

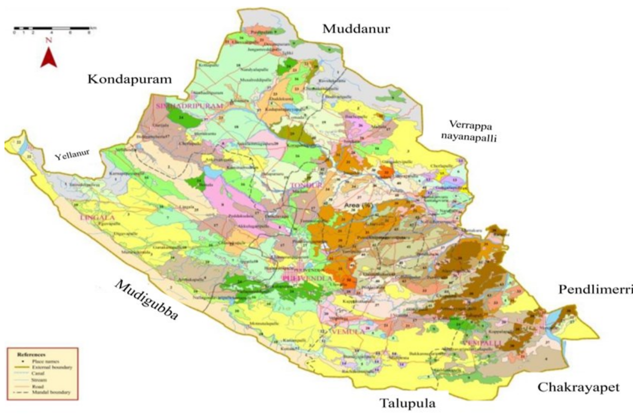

Figure 10. Soil map of Pulivendula tehsil, Kadapa district (Number in mapping units and its description is given in Table 3).

Table 4. Area and extent of soil-land form associations.

Land form	Soil mapping unit	Area		Soil loss (t/ha/year) / soil erosion risk	SQ1
		ha (hectares)	Per cent (%)		
Hills and ridges	1. Rockoutcrops (R)-Kanampalli (Kpl)	7953	6.18	25.11/high	18
	2. Rockoutcrops®- -Ganganapalle (Ggp)	7464	5.80	57.94/high	20.8
	3. Rockoutcrops®-Rachanakuntapalle(Rkp)	24939	19.39	9.91/high-medium	16
	4. Rockoutcrops®--Lingala(Lgl)	6410	4.98	102.80/extremely high	18.8
	5. Rachanakuntapalle(Rkp) – rock-outcrops®	1333	1.04	8.93/high medium	24
	6. Ganganapalle(Ggp)-Rockoutcrops®	677	0.53	57.94/ extremely high	31.2
	7. Rockoutcrops®-Mupendranpalle (Mpl)	3572	2.78	8.6/high medium	15.6
	8. Mupendranpalle(Mpl)- Rockout-crops®	2464	1.92	8.56/ high medium	23.4
Interhill basin	9. Tallalapalle(Tlp)	1829	1.42	8.97/ high medium	42
	10. Murarichintla(Mct)	1934	1.50	8.90/ high medium	49
	11. Tatireddipalle(Trp)	788	0.61	1.33/low medium	47
	12. Kottalu(Ktl)	372	0.29	3.46/ medium	37
	13. Santhakovur(Skv)	548	0.43	11.84/high	44
	14. Murarichintala(Mct)-Tallapalle (TlP)	508	0.39	8.92/ high medium	46.2
	15. Cherlapalle(Cpl)	184	0.14	5.27/ high medium	46
	16. Balapanur(Bpr)	6559	5.10	24.23/very high	52
	17. Simhadripuram(Spm)	7583	5.90	1.82/low-medium	54
	18. Simhadripuram(Spm)- Agra-haram(Ahm)	9125	7.10	2.68/ medium	55.6
	19. Balapanur(Bpr)-Sunkesula(Skl)	4294	3.34	3.65/ medium	54
Upland rain-fed areas	20. Vemula(Vml)	1667	1.30	7.65/ high medium	57
	21. Velpula(Vpl)	1326	1.03	4.12/ medium	58
	22. Parnapalle(Prp)	446	0.35	1.36/low-medium	59
	23. Agraharam(Ahm)	2690	2.09	3.59/ medium	58
	24. Sunkesula(Skl)	2778	2.16	2.97/ medium	57
	25. Agraharam(Ahm)-Sunkesula (Skl)	802	0.62	3.61/medium	57.6
	26. Agraharam(Ahm)-Simhadripuram(Spm)	369	0.29	2.78/medium	56.4
	27. Sunkesula(Skl)-Simhadripuram (Spm)	741	0.58	2.65/medium	55.8
	28. Velpula(Vpl)- .Vemula(Vml)	712	0.55	5.36/high medium	57.6

Table 4. Continued...

Land form	Soil mapping unit	Area		Soil loss (t/ha/year) / soil erosion risk	SQ1
		ha (hectares)	Per cent (%)		
Colluvial-alluvial pedi-plains	29. Bhadrampalle(Bpl)- Agadur (Agd)	788	0.61	19.34/high	55.2
	30. Tondut(Tdr)-Pernapadu(Ppd)	1351	1.05	85.36/ extremely high	53.6
	31. Tondur(Tdr)	3568	2.77	102.80/ extremely high	56
	32. Agadur(Agd)	633	0.49	1.86/low -medium	54
	33. Pernapadu(Ppd)-Gondipalle (Gpl)	853	0.66	5.68/high -medium	58.8
	34. Tondur(Tdr)-Agadur(Agd)	709	0.55	90.56/ extremely high	55.2
	35. Pulivendula(Pvd)-Pernapadu (Ppd)	101	0.08	15.32/high	50
	36. Goturu(Gtr)-Gondipalle(Gpl)	1501	1.17	2.75/low-medium	63
	37. Pernapadu(Ppd)	3689	2.87	17.31/high	50
	38. Pernapadu(Ppd)- Tondur(Tdr)	4358	3.39	85.36/ extremely high	52.4
	39. Gondipalle(Gpl)	1683	1.31	3.10/ medium	72
	40. Goturu(Gtr)	1707	1.33	1.33/low-medium	57
	41. Agadur(Agd)- Pernapadu(Ppd)	3613	2.81	15.36/high	52.4
	42. Bhadrampalle(Bpl)-	448	0.35	24.23/very high	56
	43. Pulivendula(Pvd)	3540	2.75	17.31/high	50
	Total	128609	100		

The undulating uplands cover 39092 ha (30.4%of area) with 12 soil mapping units. The moderately shallow, well drained Vemula soils (20-1,667 ha, 1.2%) are calcareous and strongly alkaline with clay surface texture and gravelly clay subsoil. The mapping units namely Velpula soils (21- 1,326 ha, 1.0%), Parnapalle in Lingala mandal (22- 446 ha, 0.3%), Velpula-Vemula association in Tondur mandal are widely occurring (28-712 ha, 0.5%). This mapping unit is associated with deep, moderately well drained, calcareous, strongly to moderately alkaline black soils with high shrink-swell potentials. Soils of colluvic and alluvial plains cover 28542 ha (22.19% of total land area) with series association of Tondur-Pernapadu (30), Pernapadu-Gondipalle association (33), Goturu-Gondipalle association (36) and Agadur-Pernapadu association (41).

Estimation of soil erosion

The annual soil loss was estimated by integrating rainfall erosivity, soil erodibility, topography, cover management, and supporting factors as used in USLE. Six classes of soil erosional mapping units are identified in the study area (Table 4). Based on area estimations, the soil erosion risk zones are arranged in ascending order as : high-medum (39142 ha, 31.16%) > high (276696 ha, 22.05%) > medium (23378 ha, 18.6%) > extremely high (16364 ha, 13.03%) > low-medium (12025 ha, 9.57%) > very high (7007 ha, 5.58%).when data arranged as per landform wise, three soil erosion risk zones are delineated viz., high-medium, high and extremely high in hills and ridges. The high-medium soil loss zone covers 32308 ha (25.13% of total area) followed by 15417ha under high erosion risk zone (11.98%) and off 7087 ha (5.51%) under extremely high erosion risk zone. The mean soil loss 34.97 ± 34.75 t/ha/year to categorize as very high erosion risk zone in hills and ridges due to high LS factor and slope gradient > 30 %. The interhill basin has 20 soil mapping units covering 35.19 % of total area (45255 ha) with soil loss of 115 t/ha/year. The mean soil loss is 10.96 t/ha/year to categorize as high erosion risk with a deviation of 23.82 t/ha/year. Out of 20 SMUs, 7 are categorized as medium erosion risk zone with mean soil loss of 3.25 ± 0.55 t/ha/year. The estimated area under medium class is 22497 ha (17.5% of total area). The six SMUs under high-medium class covers 6843ha (5.3%) with mean soil loss of 12.87 ± 12.87 t/ha/year. This class has sum of soil loss of 45.07 t /ha/year. Only three SMUs are categorized under low-medium erosion risk zones with total soil loss of 4.51 t/ha/year in an area of 8817ha (6.86% of total area). The mean soil loss is 1.503 ± 0.27 t/ha/year with variation of 18.26 per cent. The SMU Balapanur (16) is classified as very high erosion risk zone covering 6559 ha (5.1%) and Santhakovur (13) under high-risk covering 548 ha (0.43%). This landscape unit is mostly used for groundnut-banana based cropping systems in the region wherein crop management factor and soil erodibility factor decides the differential rates of erosional status. The fifteen SMUs in colluvial- alluvial pediplains cover 28542 ha (22.19%) with total soil loss of 487 t/ha/year and mean of 32.45 ± 37.39 t/ha/yr. The five SMUs under high erosion risk cover 11731 ha (9.12%) with a total soil loss of 84.64t/ha/yr and mean of 16.92±1.66 t/ha/yr. The four SMUs in colluvial-alluvial pediplains are classified under extremely eroded zone and covers 9986 ha (7.76%) with the total soil loss of 364 t/ha/yr and mean of 91.02 ± 8.23 t/ha/yr. The per cent area under low-medium erosion class is 1.66 (2134ha) and of high-medium erosion class in Pernapadu-Gondipalle (33) unit with an area of 853ha (0.66%). The variation in the results may be attributed to the varying soil factors in the different landscape units. In the study area, as expected, high erosion rate was recorded in the steeper slope area that ranges from 30 to 83% and the use of agricultural lands. The focus is for soil conservation practices in highly eroded areas. Due attention must be given for sustainable land management strategies considering the terrain attributes, status of land use cover and interest of the local community. Agroforestry, terracing, cut and carry system can be integrated to manage erosion prone areas of steep hills of Palakonda range of Pulivendula.

Soil quality assessment

The SQIs for every soil mapping unit of Pulivendula tehsil are figured out and presented in Table 4. These soils are grouped as High (% Q rating > 65), medium (% Q rating 35 to 65) and low (< 35% Q rating). The hills and ridges have 8 units with medium SQI values. The soil units have an association of shallow soils with rock outcrops. Twenty two soil units in inter hill basin are rated as medium to high quality. The soils in this landform show a strong positive correlation of pH with exchangeable Ca due to calcareousness. In colluvio-alluvial sectors, 15 units are evaluated as medium level of soil quality with parameters viz., soil pH, Zn and Olsen's P below critical level and remaining units are rated as high.

Land use anomalies and site-specific suitability

Suitability for Groundnut (*Arachis hypogeae***)**

The suitability evaluation for groundnut shows that only 23 soil mapping units are moderately suitable (Table 5) with the restrictions of rooting depth (r), topography (t) and salt content (z). The moderately suitable soil mapping units cover 56224ha (43 % of total area) consisting of 13 soil consociations (31501 ha, 24.49% of total area) and 10 soil associations (24723 ha, 19.22% of total area). The suitability analysis shows that 43% of total area is good for groundnut cultivation. This crop is extensively cultivated in

Table 5. Soil-site suitability for Groundnut.

Suitability subclass	Landform	Soil mapping unit	Ground nut area	
			ha	%
S2tz	Interhill basin	Murarichintala (10)	1934	1.5
		Kottalu(12)	372	0.3
		Total	2306	1.8
	Gently sloping midlands	Balapanur(16)	6599	4.9
		Simhadripuram (17)	7583	5.7
		Simhadripuram-Agraharam(18)	9125	6.8
		Parnapalli(22)	446	0.3
		Agraharam(23)	2690	2.0
		Agraharam - Simhadripuram (26)	369	0.3
		Total	26812	20.0
	Colluvic-alluvial sector	Agadur(32)	633	0.5
		Tondur – Agadur(34)	709	0.5
		Pernapadu(37)	3689	2.8
		Pernapadu – Tondur(38)	4358	3.3
		Agadur – Pernapadu(41)	3613	2.7
		Bhadrampalli(42)	448	0.3
		Total	13450	10.1
S2zg	Gently sloping midlands	Vemula(20)	1667	1.2
		Velpula(21)	1326	1.0
		Velpula – Vemula(28)	712	0.5
		Total	3705	2.7
S2rtz	Interhill basin	Tatireddipalli(11)	788	0.6
		Santakovur(13)	548	0.4
		Total	1336	1.0
	Gently sloping midlands	Balapanur - Sunkesula(19)	4294	3.2
		Sunkesula(24)	2778	2.1
		Agraharam – Sunkesula (25)	802	0.6
		Sunkesula – Simhadripuram(27)	741	0.6
		Total	8615	6.5

Vempalle (6894 ha, 27.39% of cultivated area) and Vemula (3613ha, 17.29% of cultivated area) mandals where groundnut is grown in sandy loam to clay loam soils**.**

Suitability for banana

The suitability of 43 soil mapping units for banana is evaluated using the criteria of Sys, *et al*. (1993). The SMU's from 1 to 8 in hills and ridges (54812ha, 42.62% of total area) are not suitable for banana cultivation but respond well to inputs and conservation measures. The twenty soil mapping units in interhill basin covers 45255 ha (35.19% of total area). Among 20 SMUs, only 8 SMUs (viz., 12, 18, 21, 23, 24, 25, 26 and 28) are moderately suitable but needs careful management of organic carbon. This unit covers 14.13 per cent of area in interhill basin (18174 ha) while 7 SMUs (22688 ha,17.65% of area), viz., 11,13,14,17,19,20 and 27) are marginally suitable with limitation of calcium carbonate, low organic carbon, strong alkalinity, coarse fragments and low available K and DTPA-Zn. Fifteen soil mapping units (SMU 29 to 43) on colluvio-alluvial plains (28542 ha, 22.19%) have very deep, moderately well drained, calcareous and strongly to moderately alkaline black soils with high shrink-swell potentials. Only five SMUs (32, 38, 40, 41 and 43) are marginally suitable for banana (Table 6). The results from land evaluation for drip irrigation shows that among 13 units are evaluated as marginally suitable for banana are evaluated. Nine SMUs are highly suitable (34502 ha) since eight SMUs (13882ha) are of moderately suitable.

Conclusions and recommendations

In the present study, Pulivendula tehsil of YSR Kadapa district is selected to identify visual signatures of dry land degradation. The land resource data on 1:25000 scales was used . The field investigations in selected sites were made and analyzed the regional climatic and crop data in support of objectives of the study. The following conclusions were drawn as given under:

- The mean monthly rainfall over 109 years is 679.59 ± 237.52mm. The south west monsoon rainfall is and 340.69mm with a deficit of 60mm to that critical rainfall of 400mm (50.28% of total rainfall). The mean air temperature is favourable for groundnut with values of 30.7^{0}C to 36.9^{0}C. The region has an aridity index of 11.29 to 14.25 indicating semiarid conditions. It is found that 64% of cases in June, there is no risk of pluvial erosion, whereas 50% of cases in September/October (43%) have favourable for triggering pluvial linear erosion.
- The soils identified and classified under four orders (Alfisols, Entisols, Inceptisols and Vertisols), five suborders (Ustalfs, Orthents, Aquepts, Ustepts and Usterts) seven greatgroups (Paleustalfs, Rhodustalfs, Haplustalfs, Ustorthents, Halaquepts, Haplustepts and Haplusterts), twelve sub-groups, eighteen families and twenty five series. Alfisols cover about 6367 ha (4.8 %), Entisols about 5477 ha (4.1 %), Inceptisols 47342 ha (35.5 %) and Vertisols 31118 ha (23.3 %). The soil map of 43 mapping units was made using GIS.
- The soils are grouped into five depth classes and eight textural classes.. The mean clay for A

Table 6. Suitability of soil mapping units for banana under drip irrigation.

Land form	Soil mapping unit	Area		Banana		Drip	
		ha (hectares)	Per cent (%)	Rat-ing	Suitabil-ity class	Rat-ing	Suitabil-ity class
Hills and ridges	1. Rockoutcrops (R)-Kanampalli(Kpl)	7953	6.18	3.34	N2	17.96	N2
	2. Rockoutcrops®- -Ganganapalle(Ggp)	7464	5.80	9.65	N2	21.60	N2
	3. Rockoutcrops®-Rachanakuntapalle(Rkp)	24939	19.39	3.72	N2	24.30	N2
	4. Rockoutcrops®--Lingala(Lgl)	6410	4.98	4.26	N2	25.52	N2
	5. Rachanakuntapalle (Rkp) – rockoutcrops®	1333	1.04	4.12	N2	53.20	N2
	6. Ganganapalle(Ggp)-Rockoutcrops®	677	0.53	16.40	N2	33.25	N2
	7.Rockoutcrops®-Mupendranpalle(Mpl)	3572	2.78	15.60	N2	29.93	N2
	8. Mupendranpalle(Mpl) - Rockoutcrops®	2464	1.92	11.32	N2	76.95	S1
Interhill basin	9. Tallalapalle(Tlp)	1829	1.42	14.21	N2	90.25	S1
	10. Murarichintla(Mct)	1934	1.50	15.83	N2	85.50	S1
	11. Tatireddipalle(Trp)	788	0.61	49.42	S3	95.00	S2
	12. Kottalu(Ktl)	372	0.29	69.04	S2	68.40	S1
	13. Santhakovur(Skv)	548	0.43	41.42	S3	72.20	S1
	14. Murarichintala(Mct)-Tallapalle(TlP)	508	0.39	43.73	S3	95.00	S3
	15. Cherlapalle(Cpl)	184	0.14	19.81	N1	85.50	S1
	16. Balapanur(Bpr)	6559	5.10	41.18	S3	95.00	S1
	17. Simhadripuram (Spm)	7583	5.90	43.73	S3	90.25	S1
	18. Simhadripuram (Spm)- Agraharam (Ahm)	9125	7.10	61.29	S3	67.50	S1
	19. Balapanur(Bpr)-Sunkesula(Skl)	4294	3.34	52.89	S3	56.53	S1
	20. Vemula(Vml)	1667	1.30	40.00	S3	85.50	S2
	21. Velpula(Vpl)	1326	1.03	68.64	S2	85.74	S1
	22. Parnapalle(Prp)	446	0.35	30.78	N1	90.25	S2
	23. Agraharam(Ahm)	2690	2.09	76.71	S2	90.25	S1
	24. Sunkesula(Skl)	2778	2.16	64.60	S2	90.25	S2
	25. Agraharam(Ahm)-Sunkesula(Skl)	802	0.62	71.87	S2	80.75	S2

Table 6. Continued...

Land form	Soil mapping unit	Area		Banana		Drip	
		ha (hectares)	Per cent (%)	Rating	Suitability class	Rating	Suitability class
Interhill basin	26. Agraharam(Ahm)-Simhadripuram(Spm)	369	0.29	66.82	S2	17.96	s1
	27. Sunkesula(Skl)- Simhadripuram(Spm)	741	0.58	58.34	S3	21.60	S2
	28. . Velpula(Vpl)- . Vemula(Vml)	712	0.55	61.16	S2	24.30	S2
Colluvial-alluvial pediplains	29. Bhadrampalle(Bpl)-Agadur(Agd)	788	0.61	29.84	N1	25.52	S2
	30.Tondut(Tdr)-Pernapadu(Ppd)	1351	1.05	31.12	N1	53.20	S1
	31.Tondur(Tdr)	3568	2.77	29.07	N1	33.25	S1
	32. Agadur(Agd)	633	0.49	48.45	S3	29.93	S1
	33.Pernapadu(Ppd)-Gondipalle(Gpl)	853	0.66	29.17	N1	76.95	S2
	34. Tondur(Tdr)- Agadur(Agd)	709	0.55	34.88	N1	90.25	S1
	35.Pulivendula(Pvd)-Pernapadu(Ppd)	101	0.08	23.27	N2	85.50	S1
	36.Goturu(Gtr)-Gondipalle(Gpl)	1501	1.17	33.80	N1	95.00	S1
	37. Pernapadu(Ppd)	3689	2.87	34.20	N1	68.40	S1
	38. Pernapadu(Ppd)-Tondur(Tdr)	4358	3.39	32.15	N1	72.20	S1
	39. Gondipalle(Gpl)	1683	1.31	22.72	N1	95.00	S3
	40. Goturu(Gtr)	1707	1.33	41.18	S3	85.50	S1
	41. Agadur(Agd)- Pernapadu(Ppd)	3613	2.81	42.75	S3	95.00	S1
	42. Bhadrampalle(Bpl)-	448	0.35	17.44	N2	90.25	S1
	43. Pulivendula(Pvd)	3540	2.75	15.99	N2	67.50	S1
	Total	128609	100			56.53	

horizons is 39.64±14.25 % and a range of 12.7% in P18 to 60.2% in P21. These soils are slightly to strong alkalinity (pH 8.5) with mean organic carbon of 7.26 ± 3.13 gkg^{-1} and mean calcium carbonate of 87.62 ± 46.57g/. The high pH (>9.0) in B horizons have strong positive correlation with $CaCO_3$(r = 0.52**) and exchangeable sodium (r = 0.39* table value of 0.37 DF of 45). The mean organic carbon is 13.58 ± 4.24 gkg^{-1} showing negative correlation with pH (r = - 0.55**, p = 0.01level, table value of 0.48) and positive with exchangeable sodium (r = 0.38*, p =0.05 level, table value of 0.38). The mean CEC is 23.93 ± 7.64 coml.(+)kg^{-1} in soils on quartzite as against the soils on shale with mean CEC of 30.52 ± 13.12 coml.(+)kg^{-1}. The data shows that seventy two per cent of soils have high (48%) to very high CEC (24%) and confine to gently sloping areas. The one way ANOVA analysis shows that there is a significant difference between the horizons for sand, clay, organic carbon and CEC ($p < 0.01$) where as pH, EC and ESP at $p < 0.05$ level.

- The results of erodibility of hill land soils show that the soils with a textural sequence of scl-cl (SMU-1, 3 &5,) have high (SMU-1) to moderate erodibility (SMU3&5). The SMU 2, 6, 7 & 8 have textural class of sandy clay to clay with low to moderate erodibility. The highly erodible soils (SMU -1) cover 7953 ha (6.18%), moderately erodible soils (SMU 2, 3, 5& 6) of 34413 ha (26.76%) and low erodible soils of 12446 ha (9.68%).
- The shallow soils on hills and ridges have 8 units with medium quality SQI. The 22 units in inter hill basin are rated as medium to high quality. The 'good growth plan for groundnut demands drought tolerant varieties suitable for three dominant landscape positions such as hills and ridges (54812ha, 42.62% of total area), interhill basins (45255ha, 35.19%of total area) and colluvio - alluvial landforms (28542ha, 22.19% of total area. The red-black soils in the region have low available nitrogen, 47% under low available phosphorus and 74% as high status of available potassium but, deficit in iron and zinc. The deep black soils with sodic enriched clay are well distributed in north central parts of Pulivendula (23533 ha,18.29% of total area). These soils are weakly to moderately susceptible to water erosion but have high erosion risk and high erodibility covering 16364ha (13.03% of total area) in hilly region of Pulivendula.
- The results from suitability analysis of banana under drip irrigation show that 56091 ha of land in interhill basins and colluvio-alluvial deposits are evaluated as suitable (S2 and S3) for banana as against the current area of 22000ha. Further the study shows that 34502 ha of land is evaluated as highly suitable for drip irrigation system. We suggested land conservation directives such as construction of bench terraces with rocks and planted with vetiver grass on the edges of the terrace.
- The results from the study led to the conclude that combining crop residue with organic amendment and runoff hedges is the best treatment for steep slope areas, although it is crucial to manage the pigeon-pea (runoff) hedges to achieve higher groundnut yield. The agropedological approach facilitates to capture a greater range of climatic conditions and evaluate the biophysical and socio-economic benefits of the most promising SLM techniques such as residue mulch combined with pigeon pea hedges against the traditional baseline practice of groundnut - pigeon pea intercropping. It is strongly advocated in semi-arid regions to have long-term historic rainfall statistics to provide a unique rainfall scenarios to express the agricultural and soil erosion risk associated with climate variability.

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Abbreviations

AP =Andhra Pradesh, CV= coefficient of variation, CVR RFT = climatic vulnerability index for rainfed tropics, FAO=Food and Agriculture Organization, GIS =Geographical information system, ha = hectare, Idm =De Martonne aridity index (IDM), IRS = Indian Remote Sensing Satellite, LGP = length of growing period, LISS = linear imaging self scanning sensor, NDVID= normalized difference in vegetation index, SD=standard deviation, SMU=soil mapping unit, SPI =standardized precipitation index, SQI=soil quality rating, t=tonne, USDA=United States Department of Agriculture, USLE: Universal Soil Loss Equation, VCI= vegetation condition index, Yr = year.

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