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Review Article

Diversity of Ecosystem Types in India: A Review

J S SINGH[1] and R K CHATURVEDI*[,2]

[1]*Ecosystems Analysis laboratory, Department of Botany, Banaras Hindu University, Varanasi 221 005, India*

[2]*Centre for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun, Mengla, Yunnan 666303, China*

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India is home to an unusually large number of endemic species and ranks sixth among the 12 megabiodiversity centers of the world. Four terrestrial biodiversity hot spots (Himalaya, Indo-Burma, Western Ghats and Sri Lanka, and Sundaland) partly lie in India. The 27 distinct biogeographic provinces, and the variety of life zones and floral groups result in equally diverse vegetation and ecosystem types. The forest ecosystems are markedly diverse and have been classified into six 'major groups' ranging from tropical to alpine, 16 'groups' and more than 200 'group categories'. The grassland ecosystems are categorized into five major grass cover types. There are 1193 wetlands covering a total area of 3.9 million hectares in 274 districts. Total area of coral reefs comprises 2,375 sq km. India is one of the eight Vavilov's centers of origin of cultivated plants in the world and has twenty distinct agro-ecosystems, characterized by variations in edaphic, climatic and geographic features, and consequently a diverse cropping pattern. In this article we give an overview of the vast array of broad ecosystem types that occur in India. We also briefly discuss the human impacts on the health of country's ecosystems and the ecosystem conservation scenario.

Keywords: India; Ecosystem Diversity; Forests; Grasslands; Wetlands; Agricultural Zones

Introduction

India is situated north of the equator between 66°E to 98°E long. and 8°N to 36°N lat. It is bordered by Nepal, China and Bhutan in the north; Bangladesh and Myanmar in the east; the Bay of Bengal in the south east; the Indian Ocean in the south; the Arabian Sea in the west; and Pakistan in the north-west. Total land area of India is 3.3 million square kilometers and it is the seventh largest country in the world. It is 2,933 kms wide and 3,214 kms long. In the north, Himalayan ranges separate the Indian sub-continent from the rest of Asia. Down towards south lies the Indo-Gangetic plains which is further crossed over by the Vindhyachal mountains. Next lies the Deccan Peninsula which is bounded by Arabian sea to the south-west and the Bay of Bengal to the south-east. The southern-most tip of the country projects into the Indian Ocean. Mountains cover an area of around 100 mha, arid and semi-arid zones are spread over 30 mha and the coastline is about 8000 km long (MoEF, 2009).The three great rivers of Northern India – the Indus, the Ganges and the Brahmaputra, have originated from the Himalaya. The vast area of the Indo-Gangetic plains between the Himalaya and the Deccan plateau has been filled up by the alluvium transported from the Himalaya by the great river system. The Mahanadi, Godavari, Krishna, Kaveri and the Pennar in the eastern coast and the Narmada, Tapti, Sharavati, Netravati, Bharatapuzha, Periyar and the Pamba in the west coast have created a variety of deltas and flood-plains. India represents great geological, geomorphological, climatic, biotic and cultural diversity. The vast diversity of climatic features (tropical to arctic) and habitats (plains, wetlands and mountains) has led to a wide variety of flora and fauna, which form diverse ecosystems.

*Author for Correspondence: E-mail: ravikantchaturvedi10@gmail.com; ravi@xtbg.ac.cn

In this article we give an overview of the vast array of broad ecosystem types that occur in India.

Biogeographical Regions and Holdridge Life-zones

India is represented by two 'Realms'- Palearctic Realm (Himalayan region) and Malayan Realm (rest of the sub-continent), and ten biogeographic regions and 27 biogeographic provinces (Fig. 1, Table 1). The geographical analysis (Roy *et al.*, 2006) reveals 19 Holdridge life-zones, seven biomes and 19 sub-biomes (Fig. 2). The biomes, as per Roy *et al.* (2006) are (i) Tropical Rain Forest, (ii) Tropical Wet Forest, (iii) Tropical Moist Forest, (iv) Tropical Dry Forest, (v) Tropical Thorn Woodland, (vi) Tropical Desert and (vii) Himalayan Temperate Tundra.

India is home to an unusually large number of endemic species and ranks sixth among the 12 mega biodiversity centers of the world. Four terrestrial biodiversity hot spots (Himalaya, Indo-Burma, Western Ghats and Sri Lanka, and Sundaland) partly lie in India. In terms of plant diversity, India ranks tenth in the world and fourth in Asia. India has over 45,500 plant species, which is nearly 11% of the world's known floral diversity. There are remote geographical areas which are yet to be comprehensively explored; and many organisms especially in lower groups such as bacteria, fungi, algae, lichens and bryophytes are yet to be described. New plant species, however, are continually being discovered in the country. For example, 41 plant taxa were discovered from diverse bio-geographic zones of India during 2007 by Botanical Survey of India (BSI) and other researchers. Similarly in cryptogams, the National Botanical Research Institute (NBRI), Lucknow described 11 new species during 2007-08. Under the All India Coordinated Project for capacity building in Taxonomy (AICOPTAX), funded by the Ministry of Environment and Forests (MoEF), 493

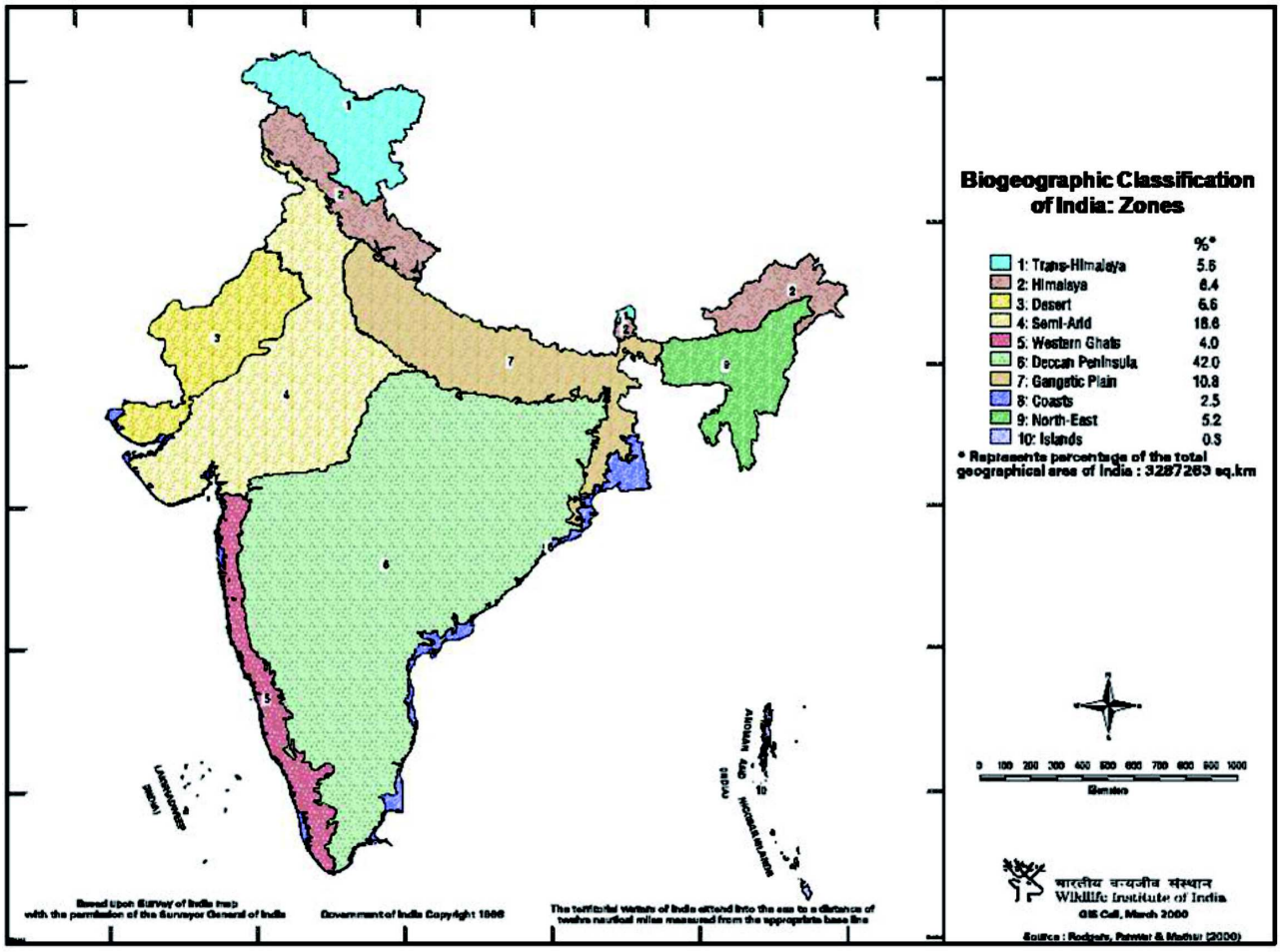

Fig. 1: Biogeographic zones of India (Source: Rodgers *et al.*, 2000)

Table 1: Biogeographic zones of India (Source: MoEF, 2009)

S.No.	Biogeographic Zones	Biogeographic Provinces	% of geographical area
1.	Trans Himalaya	1A: Himalaya - Ladakh Mountains	3.3
		1B: Himalaya -Tibetan Plateau	2.2
		1C: Trans - Himalaya Sikkim	<0.1
2.	The Himalaya	2A: Himalaya - North West Himalaya	2.1
		2B: Himalaya - West Himalaya	1.6
		2C: Himalaya - Central Himalaya	0.2
		2D: Himalaya - East Himalaya	2.5
3.	The Indian Desert	3A: Desert – Thar	5.4
		3B: Desert – Katchchh	1.1
4.	The Semi Arid	4A: Semi - Arid - Punjab Plains	3.7
		4B: Semi - Arid – Gujarat, Rajputana	12.9
5.	The Western Ghats	5A: Western Ghats - Malabar Plains	2.0
		5B: Western Ghats -Western Ghats Mountains	2.0
6.	The Deccan Peninsula	6A: Deccan Peninsular - Central Highlands	7.3
		6B: Deccan Peninsular - Chotta Nagpur	5.4
		6C: Deccan Peninsular - Eastern Highlands	6.3
		6D: Deccan Peninsular - Central Plateau	12.5
		6E: Deccan Peninsular - Deccan South	10.4
7.	The Gangetic Plains	7A: Gangetic Plain - Upper Gangetic Plains	6.3
		7B: Gangetic Plain - Lower Gangetic Plains	4.5
8.	The Coasts	8A: Coasts - West Coast	0.6
		8B: Coasts - East Coast	1.9
		8C: Coasts – Lakshdweep	<0.1
9.	Northeast India	9A: North - East - Brahamputra Valley	2.0
		9B: North - East – North East Hills	3.2
10.	Islands	10A: Islands – Andamans	0.2
		10B: Islands – Nicobars	0.1

taxa new to science have been discovered (MoEF, 2009). Important floral groups found in India are summarized in Table 2, and important wild fauna in the 10 biogeographic regions are listed in Table 3.

The 27 distinct biogeographic provinces, the variety of life-zones and floral groups result in equally diverse vegetation and ecosystem types. The broad ecosystem types are briefly described below.

Forest Ecosystems

According to the latest report of the forest survey of India (FSI, 2016), forest and tree cover of the country in 2015 was 702979 km^2 or 24.16% of the geographical area (21.34% forest cover + 2.82% tree cover). Of the total forest cover, very dense forest (canopy cover >70%) was only 2.5% of the geographical area, moderately dense forest (canopy cover 40-70%) occupied the maximum area followed by open forest (canopy cover 10-40%) There is an additional 1.28% of scrub vegetation. The forest ecosystems are markedly diverse. Champion and Seth (1968) classified India's forests into six 'major groups' ranging from tropical to alpine, 16 'groups' and more than 200 'group categories' (Table 4). According to Champion and Seth's classification, forest type is a unit of vegetation having physiognomic and structural features so pronounced that it appears distinct from

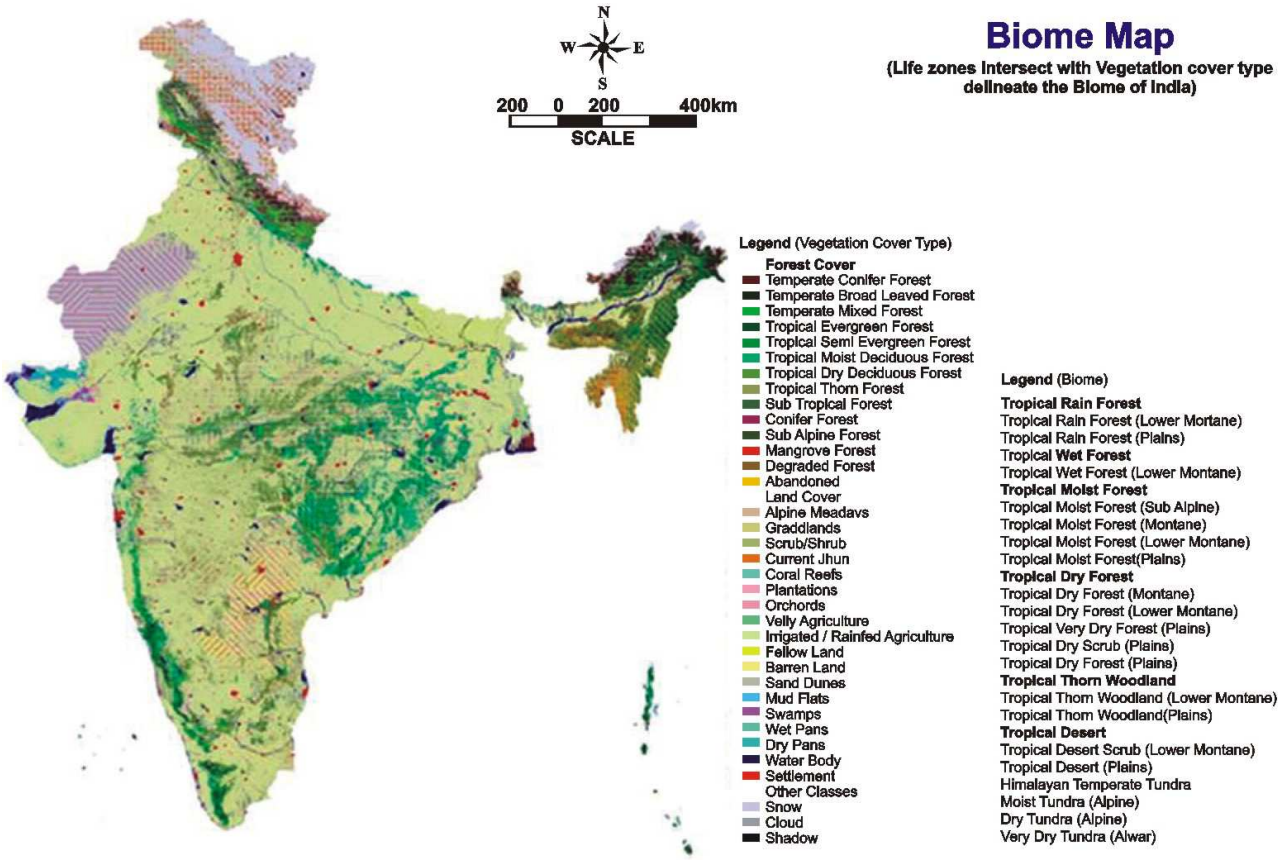

Fig. 2: Biome map of India (Source: Roy *et al.*, 2006)

other units. Each forest group usually has a southern and a northern counterpart which differ in species composition. The forest groups in themselves are highly diverse, for example the group 5th in Table 4, has 5 subgroups and 23 categories (Table 5). Of the 16 forest groups, the tropical deciduous accounts for 38.2 % of the total forest area (Fig. 3). The distribution of woody species in this forest group is determined by small-scale variations in environmental variables resulting into patchiness in communities (Chaturvedi *et al.*, 2011a; Chaturvedi and Raghubanshi, 2014; Chaturvedi and Raghubanshi, 2015). Due to the patchy distribution of tree assemblages, tropical dry forests generally show uneven distribution of aboveground tree biomass, carbon density and carbon accumulation (Chaturvedi *et al.*, 2011b; Chaturvedi *et al.*, 2011c; Chaturvedi *et al.*, 2012; Chaturvedi *et al.*, 2017a). The deciduous forest is species poor but has been shown to be a mosaic of communities with distinct species composition; each of these communities is distributed in non-contiguous patches leading to immense diversity (Jha and Singh, 1990). A detrended

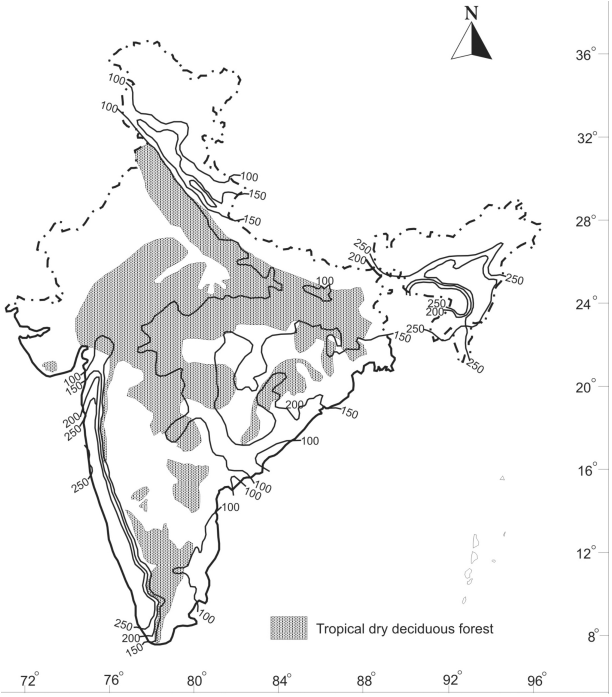

Fig. 3: Potential distribution of tropical dry deciduous forest in India. The contour lines represent annual rainfall in centimetres (Source: Singh and Singh, 2011)

Table 2. Important floral groups of India (Adapted from MoEF, 2009)

Floral groups	Species/Genera/ Families	Important Families (no. of species)	Remarks
Angiosperms	about 17,527 species in 2,984 genera and 247 families	Poaceae (1291); Orchidaceae (1229); Leguminosae (1225); Asteraceae (892); Rubiaceae (616); Cyperaceae (545); Euphorbiaceae (527); Acanthaceae (510)	India contains more than 7% of the world's known flowering plants; about 4,900 species are endemic to the country; Labiatae and Compositae are more abundant in the temperate regions while the rest are largely tropical in distribution
Gymnosperms	about 67 species in 20 genera	Pinaceae (15); Cupressaceae (13); Ephedraceae (7); Gnetaceae (5)	species of *Gnetum* and *Cycas* are mostly confined to North Eastern region, Eastern and Western Ghats, and Andaman and Nicobar Islands
Pteridophytes	about 1200 species in 204 genera	Polypodiaceae (137); Dryopteridaceae (125); Athyriaceae (97); Thelypteridaceae (83); Selaginellaceae (62)	about 17% of the species are endemic to India; north-eastern region (including Eastern Himalaya) contains about 845 species, followed by South India (including Eastern and Western Ghats) with 345 species and North India (including Western Himalaya) with 340 species; dominant genera are *Selaginella* (62 species), *Asplenium* (45 species) and *Polystichum* (45 species)
Bryophytes	about 2500 species in 482 genera and 106 families	Lejeuneaceae (155); Pottiaceae (129); Dicranaceae (119); Bryaceae (98); Sematophyllaceae (92)	second largest group of green plants in India distributed largely in Eastern Himalaya, North-eastern India, Western Himalaya and the Western Ghats; 19 genera and 629 species are endemic to India; major component include mosses (1576 species), and liverworts and hornworts (924 species)
Lichens	about 2,223 species in 283 genera and 72 families	Parmeliaceae; Graphidaceae; Physciaceae; Usneaceae; Cladoniaceae	Western Ghats are the richest region with 800 species (38%) followed by Eastern Himalaya with 759 species (37%) and Western Himalaya with 550 species (27%)
Fungi	about 14,500 species in 2,300 genera and 250 families	Deuteromycetes (6000); Ascomycetes (3500); Basidiomycetes (3400)	maximum diversity in the Western Ghats followed by the Eastern Himalaya and the Western Himalaya; about 3500 species are endemic to the country; dominant genera are *Cercospora* (707 species); *Puccinia* (328 species); *Phyllosticta* (280 species)
Algae	about 7,175 species in 666 genera	Chlorophyceae (4,495); Cyanophyceae (1,453); Bacillariophyceae (516)	found in a variety of habitats ranging from aquatic (both fresh water and marine) to terrestrial

correspondence analysis (DCA) of 48 stands of a dry tropical forest indicated the presence of five distinct communities (Figure 4) which were associated with soil texture. Plant species in these forests have important functional traits that enable acquisition of limiting nutrients and water (Chaturvedi *et al.*, 2011b; Chaturvedi *et al.*, 2011d; Chaturvedi *et al.*, 2013; Chaturvedi *et al.*, 2014; Chaturvedi and Raghubanshi, 2013; Chaturvedi and Raghubanshi, 2016). The other predominant forest group is the moist deciduous (Group-3) covering 30.3 % of the forest area of the country, having 4 sub-groups and 15 categories (Table 4).

Tropical forests of the country are divided into a series of successively drier climatic types. Among the six major forest groups, the dense and multilayered moist tropical forests occur in the areas of high temperatures and rainfall and comprise (i) wet-evergreen forests, characterized by dense growth of tall trees, and rich in climbers, lianas, epiphytes and shrubs but poor in herbs and grasses; (ii) semi-evergreen forests characterized by dense growth of intermixed deciduous and evergreen trees and a rich carpet layer of herbs, grasses and ferns; (iii) moist-deciduous forests, characterized by the dominance of deciduous trees with a lower storey of evergreen trees and shrubs; (iv) littoral and swamp forests characterized by the dominance of halophytic evergreen plants.

Dry tropical forests comprise (i) dry-deciduous

Table 3: Important wild fauna of India. (Adapted from Singh *et al.*, 2015).

S.No.	Biogeographic zone	Important wild fauna
1.	Trans-Himalayas	Wild Yak, Ass, Gazelle, Four-Horned Antelope, Snow Leopard, Tibetan Wolf, Lesser Cat (Pallas' Cat), Fox, Marbled Pole Cat, Royals Pika,Himalayan Marmot, Black Necked Crane
2.	Himalaya	Tibetan Ass, Sikkim Stag, Musk Deer, Tahr, Beharal, Ibex, Mishmi Takin, Sun Bear,Gibbon, Binturong, Red Pandas, Lesser Cats, Jungle Fowl, Markhor, Serow
3.	Desert	Wild Ass, Desert Fox, Indian Desert Cat, Honbara Bustard, Sand Grouse, Chinkara, Blackbuck, Wolf, Caracal, Great Indian Bustard, Flamingoes
4.	Semi-Arid	Blackbuck, Chowsingha, Nilgai, Gazelle, Lions, Cheetah, Caracal, Jackal, Wolf
5.	Western Ghats	Tiger, Leopard, Dhole, Sloth Bear, Indian Elephant, Gaur, Nilgiri Langur, Lion Tailed Macaque, Platacothomys, Spiny Dormouse, Grizzled Giant Squirrel, Malabar Civet, Rusty Spotted Cat, Nilgiri Tahr, Malabar Grey Hornbill, Travancore Tortoise, Cane Turtle
6.	Deccan Peninsula	Tiger, Chital, Sambar, Nilgai, Chowsingha, Elephant, Wild Buffalo, Hard Ground Swamp Deer, Gharhial, Rusty Spotted Cat, Wolf
7.	Gangetic Plain	Nilgai, Blackbuck, Chinkara, Swamp Deer, Hog Deer, Rhino, Bengal Florican, Hispid Hare, Sambar Chital
8.	Coasts	Dungdong, Hump-back Dolphin, Salt-Water Crocodile, Batagur Basker Turtle, Huge soft-shell Estuarine turtle,
9.	North-East	Rhinoceros, Buffalo, Elephant, Swamp Deer, Hog Deer, Pygmy Hog, Hispid Hare, Hornbill, Waterfowl
10.	Islands	Andaman Pig, Nicobar Macaque, Nicobar Tree Shrew, Nicobar Megapode, Narcodium Hornbill, Nicobar Pigeon, Andaman Wood Pigeon, Nicobar Parakeet, Water Monitor, Salt Water Crocodile, Marine Turtles, Dolphins, Whales

forest, characterized by abundance of shrubs and open canopy of small trees, which experience about six months of dry period in the annual cycle; (ii) thorn forests which experience more than six months of dry period each year and are characterized by the sparse distribution of small, mostly thorny trees with abundance of shrubs. Grasses and herbs appear during the brief rainy season when trees and shrubs also develop leaves; (iii) dry-evergreen forests experiencing high temperature and small rainfall available during the summer season. Bamboos are absent from these forests but grasses and small trees are abundant.

Montane sub-tropical forests are present between the altitudes of 1000 m and 2000 m and experience cooler climate than tropical but warmer than temperate forests. Semi-xerophytic evergreen plants are predominantly present and the forests are categorized into (i) broad-leaved hill forests, characterized by abundance of climbers and epiphytic ferns and orchids, and dense growth of evergreen broad-leaved trees; (ii) pine forests, comprising the open formations of pine trees; (iii) dry-evergreen forests, mainly characterized by the presence of small-leaved evergreen plants and thorny xerophytes.

Montane temperate forests are found in areas having low temperature with comparatively high humidity. The forests comprise tall conifers or angiospermic evergreen trees laden with epiphytic mosses, lichens and ferns. These forests are categorized into three groups: (i) montane wet temperate forests which have a northern and a southern category. The northern category (Eastern Himalaya) is characterized by dense evergreen or semi-evergreen broad-leaved trees of up to 25 m height. In the southern category, trees are relatively

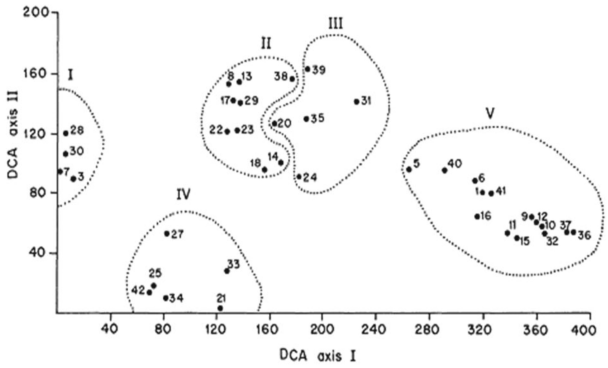

Fig. 4: DCA ordination of dry tropical forest stands (Source: Jha and Singh, 1990)

Table 4: Diversity of forest ecosystems: forest types, their dominant species, and distribution (based on Champion and Seth, 1968)

Major group	Group (characteristic features)	Area (mha)	% area	Sub-groups and their categories	Occurrence
I-MOIST TROPICAL FORESTS	1-Tropical Wet-Ever-greenForests (tall, ≥ 45 m, dense, entirely evergreen, rainfall > 3000 mm, temperature 25-30 ºC, dominated by species of *Dipterocarpus* among others)	4.5	5.8	1A-*Southern tropical wet evergreen forests* [C1-Giant evergreen forest-**Dipterocarpus alatus*; C2-Andamans tropical evergreen forest-*Dipterocarpus grandiflorus*; E1-(Andamans moist deciduous forests-*Terminalia bialata*); C3-Southern hilltop tropical evergreen forest-*Dipterocarpus costatus*; C4-West Coast tropical evergreen forest-*Dipterocarpus indicus*]	Maharashtra, Mysore, Madras, Kerala, Andamans
				1B-*Northern tropical wet evergreen forests* [C1-Assam Valley tropical wet evergreen forest-*Dipterocarpus macrocarpus.*; C2-Upper Assam Valley tropical evergreen forest: (a) *Kayea* forest, (b) *Mesua* forest; C3-Cachar tropical evergreen forest-*Mesua-Dipterocarp-Palaquium* formation]	West Bengal, Assam, Orissa
				General edaphic and seral types of wet evergreen forests [E1-Cane brakes-*Calamus* spp.; E2-Wet bamboo brakes; 2S1-Pioneer Euphorbiaceous scrub]	Maharashtra, Mysore, Madras, Kerala, Andamans, West Bengal, Assam, Orissa
	2-Tropical Semi-Ever-green Forests (dominants are deciduous, but everg-reens predominate in lower or middle canopy, may reach 40 m height, rainfall 2000-2500 mm, temperature 25-32 ºC, dominated by *Magnolia, Cinnamomum, Terminalia, Xylia*, etc.).	1.9	2.5	2A-*Southern tropical semi-evergreen forests* [C1-Andamans semi-evergreen forest-*Dipterocarpus alatus*; C2-West Coast semi-evergreen forest-*Terminalia paniculata*; C3-Tirunelveli semi-evergreen forest-*Hopea* (*Balanocarpus*) *utilis*; 2S1-West Coast secondary evergreen Dipterocarp forest-*Hopea parviflora*]	Andamans, Western Ghats, North Mumbai, Goa, South Cochin
				2B-*Northern tropical semi-evergreen forests* [C1-Assam Valley semi-evergreen forest: (1a) Assam alluvial plains semi-evergreen forest-*Eugenia formosa*, (1b) Eastern submontane semi-evergreen forest-*Schima wallichii*; 1S1-Sub-Himalayan light alluvial semi-evergreen forest-*Syzygium* (*Eugenia*) spp.; 1S2-*Syzygium* parkland- *Syzygium cerasoideum*; 2S1-(Pioneer Euphorbiaceous scrub-*Macaranga denticulata*); 2S2-Eastern alluvial secondary semi-evergreen forest-*Tetrameles nudiflora*; 2S3-Sub-Himalayan secondary wet mixed forest-*Michelia montana*; C2-Cachar semi-evergreen forest-*Dipterocarpus turbinatus*; C3-Orissa semi-evergreen forest-*Artocarpus lakoocha*]	Assam, West Bengal, Orissa
				General edaphic and seral types of semi-evergreen forests [E1-(Crane brakes-*Calamus* spp.); E2-(Wet bamboo brakes-*Dipterocarpus* spp.); E3-Moist bamboo brakes-*Terminalia species*; E4-Laterite semi-evergreen-*Xylia xylocarpa*; 2S1-Secondary moist bamboo brakes-*Oxytenanthera nigrociliata*]	Andamans, Western Ghats, North Mumbai, Goa, South Cochin, Assam, West Bengal, Orissa
	3-Tropical Moist-Deciduous Forests (dominants deciduous, lower storey trees usually evergreen, may reach 40 m height,	23.3	30.3	3A-*Andamans moist deciduous forests* [C1-Andamans moist deciduous forest-*Pterocarpus dalbergioides*; 2S1-Andamans secondary moist deciduous forest-*Canarium euphyllum*]	Andaman Islands, Nicobars
				3B-*South Indian moist deciduous forests* [C1-Moist teak-bearing forest: (1a) Very moist teak forest-*Termi-*	Maharashtra, Madhya Pradesh,

	rainfall 1200-2500 mm, temperature 25-30 ºC, may or may not bear *Tectona grandis*, or *Shorea robusta*)			*nalia crenulata*, (1b) Moist teak forest-*Tectona grandis*, (1c) Slightly moist teak forest-*Tectona grandis*; C2-Southern moist mixed deciduous forest-*Pterocarpus marsupium*; 2S1-Southern secondary moist mixed deciduous forest-*Terminalia paniculata*]	Gujarat, Mysore, Madras, Kerala
				3C-*North Indian moist deciduous forests* [C1-Very moist sal-bearing forest: (1a) Eastern hill sal forest {(i) East Himalayan sal, (ii) Khasi hill sal}, (1b) Eastern *bhabar* sal forest {(i) East Himalayan upper *bhabar* sal, (ii) East Himalayan lower *bhabar* sal}, (1c) Eastern *tarai* sal forest, (1d) Peninsular (coastal) sal forest; C2-Moist sal-bearing forest: (2a) Moist Siwalik sal forest, (2b) Moist *bhabar* sal forest {(i) *Bhabar-dun* sal, (ii) *Damar* sal}, (2c) Moist *tarai* sal forest, (2d) Moist plains sal forest {(i) Western light alluvium plains sal, (ii) App. *Chandar* sal, (iii) Eastern heavy alluvium plains sal, (iv) App. Kamrup sal}, (2e) Moist peninsular sal forest {(i) Moist peninsular high level sal, (ii) Moist peninsular low level sal, (iii) Moist peninsular valley sal}; DS1-Moist sal savannah; C3-Moist mixed deciduous forest (without sal): (3a) West Gangetic moist mixed deciduous forest-*Albizzia procera*, (3b) East Himalayan moist mixed deciduous forest-*Lagerstroemia parviflora*; 2S1-Northern secondary moist mixed deciduous forest-*Mangifera indica*; 2S2-(Secondary Euphorbiaceous scrub)-*Terminalia tomentosa*]	Uttrakhand, Uttar Pradesh, Bihar, Orissa, West Bengal, Assam, Madhya Pradesh
				General edaphic and seral types of moist deciduous forests [E1-*Terminalia tomentosa* forest; 1S1-Low alluvial savannah woodland (*Salmalia-Albizzia*); 1S2-Eastern hollock forests (*Terminalia myriocarpa*): (2a) *Terminalia-Lagerstroemia*, (2b) *Terminalia-Duabanga*]; 2S1-(Dry bamboo brakes)-*Dendrocalamus strictus*]	Uttar Pradesh, Bihar, West Bengal, Assam, Madhya Pradesh
	4-Littoral and Swamp Forests (mainly evergreen, include mangrove and freshwater swamp forests, dominated by *Rhizophora, Bruguiera, Ipomea, Phoenix, Barringtonia*, etc)	0.7	0.9	4A-*Littoral forests* [L1-Littoral forest-*Manilkara littoralis*] 4B-*Tidal swamp forests* [TS1-Mangrove scrub-*Ceriops roxburghiana*; TS2-Mangrove forest-*Rhizophora candelaria*; TS3-Saltwater mixed forest-*Heritiera minor*; TS4-Brakish water mixed forest-*Heritiera minor*; E1-Palm swamp-*Phoenix paludosa*]	Andaman and Nicobar Islands Delta of Ganges and Brahmaputra rivers
				4C-*Tropical freshwater swamp forests* [FS1-*Myristica* swamp forest-*Myristica magnifica*; FS2-Submontane hill valley swamp forest-*Eugenia* spp.; FS3-Creeper swamp forest-*Magnolia griffithii*]	Kerala, Uttrakhand, Brahmaputra Valley
				4D-*Tropical seasonal swamp forests* [SS1-Eastern seasonal swamp forest-*Altingia excelsa*; SS2-*Barringtonia* swamp forest- *Barringtonia acutangula*; SS3-*Syzygium cumini* swamp low forest; SS4-Eastern seasonal swamp low forest-*Cephalanthus occidentalis*; SS5-Eastern *Dillenia* swamp forest-*Dillenia indica*; 2S1-(*Syzygium* parkland); 2S2-(Eastern wet alluvial grassland)-*Vetiveria zizanioides*]	Brahmaputra Valley, Uttar Pradesh, Assam, West Bengal
				4E-*Tropical riparian fringing forests* [RS1-Riparian fringing forest-*Terminalia arjuna*]	Banks of bigger rivers
II-DRY TROPICAL	5-Tropical Dry-Deciduous Forests	29.4	38.2	5A-*Southern tropical dry deciduous forests* [C1-Dry teak-bearing forest: (1a) Very dry teak forest, (1b) Dry	Maharashtra, Madhya Pradesh,

FORESTS	(entirely deciduous or nearly so, rainfall 800-1200 mm, temp. 25-32ºC, some forests bear *Tectona grandis* or *Shorea robusta*, others are devoid of these species and have species of *Anogeissus* and *Terminalia*, etc.).			teak forest; C2-Dry red sanders-bearing forest-*Pterocarpus santalinus*; C3-Southern dry mixed deciduous forest-*Terminalia tomentosa*]	Andhra Pradesh, Madras, Mysore
				5B-*Northern tropical dry deciduous forests* [C1-Dry sal bearing forest: (1a) Dry Siwalik sal forest, (1b) Dry plains sal forest, (1c) Dry peninsular sal forest; C2-Northern dry mixed deciduous forest-*Acacia catechu*]	Punjab, Uttar Pradesh, Bihar, Orissa, West Bengal
				Degradation stages of tropical dry deciduous forests [DS1-Dry deciduous scrub-*Nyctanthes arbortristis*; DS2-Dry savannah forest-*Gardenia turgida*; DS3-(*Euphorbia* scrub)-*Euphorbia neriifolia*; DS4-(Dry grassland)-*Sehima nervosum*]	Maharashtra, Madhya Pradesh, Andhra Pradesh, Madras, Mysore, Punjab, Uttar Pradesh, Bihar, Orissa, West Bengal
				General edaphic types of dry deciduous forests [E1-*Anogeissus pendula* forest; DS1-*Anogeissus pendula* scrub; E2-*Boswellia* forest-*Boswellia serrata*; E3-*Babul* forest-*Acacia arabica*; E4-*Hardwickia* forest-*Hardwickia binata*; E5-*Butea* forest-*Butea monosperma*; E6-*Aegle* forest- *Aegle marmelos*; E7-Laterite thorn forest-*Gardenia* spp.; E8-Saline/alkaline scrub savannah: (8a) *Phoenix* savannah-*Phoenix sylvestris*, (8b) *Babul* savannah-*Acacia arabica*, (8c) *Salvadora-Tamarix* scrub; E9-Dry bamboo brake-*Dendrocalamus strictus*]	Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Punjab, Bihar, Kerala, Gujarat, Mysore, Madras
				General seral types of dry deciduous forests [1S1-Dry tropical riverine forest-*Terminalia arjuna*; 1S2-*Khair-sissu* forest-*Acacia catechu*; 1S3-Inundation *babul* forest-*Acacia arabica*; 2S1-Secondary dry deciduous forest-*Prosopis spicigera*]	Rajasthan, Punjab, Uttar Pradesh, Bihar, West Bengal, Assam
	6-Tropical Thorn Forests (deciduous with low thorny trees, rainfall 200-800 mm, temperature 27-30ºC, *Acacia, Balanites, Prosopis, Salvadora*, etc., predominate)	5.2	6.7	6A-*Southern tropical thorn forests* [C1-Southern thorn forest-*Acacia leucophloea*; C2-Karnatak umbrella thorn forest-*Acacia planifrons*; DS1-Southern thorn scrub-*Zizyphus xylopyrus*; DS2-Southern *Euphorbia* scrub-*Euphorbia tirucalli*]	Madhya Pradesh, Maharashtra, Madras, Mysore
				6B-*Northern tropical thorn forests* [C1-Desert thorn forest-*Prosopis spicigera*; C2-Ravine thorn forest-*Acacia leucophloea*; DS1-*Zizyphus* scrub-*Acacia leucophloea*; DS2-Tropical *Euphorbia* scrub-*Euphorbia neriifolia*]	Punjab, Uttar Pradesh, Madhya Pradesh, Gujarat, Rajasthan
				General edaphic, degraded and seral types of moist deciduous forests [E1-(*Euphorbia* scrub)-*Euphorbia neriifolia*; E2-*Acacia senegal* forest; E3-*Rann* saline thorn forest-*Prosopis juliflora*; E4-*Salvadora* scrub-*Salvadora oleoides*; DS1-*Cassia auriculata* scrub; 1S1-Desert dune scrub-*Prosopis spicigera*]	Rajasthan, Gujarat, Punjab
	7-Tropical Dry-Evergreen Forests (hard-leaved evergreen trees, rainfall 870-1200 mm, dominated by *Manilkara*, and *Memecylon*, etc.)	0.1	0.1	[C1-Tropical dry evergreen forest-*Manilkara hexandra*; DS1- Tropical dry evergreen scrub-*Memecylon edule*]	Andhra Pradesh, Madras
III-MONTANE SUB-TROPICAL FORESTS	8-Sub-Tropical Broad Leaved Hill Forests (largely evergreen, rainfall 1000-3000mm (Cherrapunji, 11000mm),	0.3	0.4	8A-*Southern subtropical broadleaved hill forests* [C1-Nilgiri subtropical hill forest-*Calophyllum elatum*; DS1-South Indian sub-tropical hill savannah (woodland)-*Dalbergia latifolia*; E1-Reed brakes-*Ochlandra wightii*; C2-Western subtropical hill forest-*Syzygium cumini*;	Kerala, Madras, Mysore, Mumbai, Rajasthan, Madhya Pradesh, Bihar, Orissa

	in southern India species of *Calophyllum, Rhododendron niligiricum*, etc. and in eastern Himalaya, species of *Quercus* predominate)			C3-Central Indian subtropical hill forest-*Carallia brachiata*; DS-(Degradation stages of southern subtropical broad-leaved hill forests)]	
				8B-*Northern subtropical broadleaved wet hill forests* [C1-East Himalayan subtropical wet hill forest-*Castanopsis tribuloides*; C2-*Khasi* subtropical wet hill forest-*Quercus* spp.; 2S1-(Assam subtropical pine forest); DS1-(Assam subtropical hill savannah woodland)]	West Bengal, Assam, Manipur, Tripura
	9-Sub-Tropical Pine Forests (pine associations predominate in low altitudes of Himalaya, rainfall 1000-3000mm, *Pinus roxburghii* (western Himalaya), *P. kesiya* (eastern Himalaya)	3.7	5.0	[C1-Himalayan subtropical pine forest: (1a) Lower or Siwalik chir pine forest-*Pinus roxburghii*, (1b) Upper or Himalayan chir pine forest-*Pinus roxburghii*; DS1-Himalayan subtropical scrub-*Carissa* spp.; DS2-Subtropical *Euphorbia* scrub-*Euphorbia royleana*; C2-Assam subtropical pine forests-*Pinus insularis*; DS1-Assam subtropical pine savannah]	Punjab, Uttrakhand, Assam, Manipur
	10-Sub-Tropical Dry-Evergreen Forests (low xerophytic forest and scrub in the foothills of western Himalaya, *Olea* and *Acacia* spp.)	0.2	0.2	[C1-Subtropical dry evergreen forest: (1a) *Olea cuspidata* scrub forest, (1b) *Acacia modesta* scrub forest; DS1-*Dodonaea* scrub-*Dodonaea viscosa*]	Jammu, Punjab
IV-MONTANE TEMPERATE FORESTS	11-Montane Wet Temperate Forests (closed evergreen high forests, rainfall 1500-> 5000 mm, in southern India shola forests (*Ternstroemia, Ilex, Rhododendron*), in eastern Himalaya *Quercus* forests with *Machilus, Acer, Rhododendron*, etc.)	1.6	2.0	11A-*Southern montane wet temperate forests* [C1-Southern montane wet temperate forest-*Ternstroemia gymnanthera*; DS1-Southern montane wet scrub-*Hypericum mysorense*; DS2- Southern montane wet grassland-*Bothriochloa pertusa*]	Madras, Kerala
				11B-*Northern montane wet temperate forests* [C1-East Himalayan wet temperate forests: (1a) Lauraceous forest-*Machilus edulis*, (1b) *Buk* oak forest-*Quercus lamellosa*, (1c) High-level oak forest-*Quercus pachyphylla*; C2-Naga hills wet temperate forests-*Magnolia* spp.]	West Bengal, Assam, Manipur, Sikkim
	12-Himalayan Moist Temperate Forests (all along Himalaya (1500-3300m altitude), rainfall 1000-2500 mm, several conifers (e.g., *Abies, Cedrus, Picea, Tsuga*) and broadleaved species (*Quercus, Rhododendron, Acer, Ulmex*, etc.), composition differs with altitude and location (western vs. eastern Himalaya)	2.6	3.4	[C1-Lower Western Himalayan temperate forest: (1a) *Ban* oak forest (*Quercus incana*), (1b) *Moru* oak forest (*Quercus dilatata*); DS1-Oak scrub: (1c) Moist deodar forest-*Cedrus deodara*, (1d) Western mixed coniferous forest (spruce, blue pine, silver fir)-*Picea* sp., *Cedrus* spp., *Abies pindrow*, (1e) Moist temperate deciduous forest-*Aesculus indica*, (1f) (Low-level blue pine forest (*Pinus wallichiana*)); DS1-Oak scrub-*Q. incana*; DS2-Himalayan temperate secondary scrub-*Plectranthus rugosus*; C2-Upper West Himalayan temperate forest: (2a) *Kharsu* oak forest (*Quercus semecarpifolia*), (2b) West Himalayan upper oak/fir forest-*Abies pindrow*, (2c) (Moist temperate deciduous forest)-*Aesculus indica*; C3-East Himalayan moist temperate forest: (3a) East Himalayan mixed coniferous forest-*Tsuga dumosa*, (3b) *Abies delavayi* forest]	Jammu and Kashmir, Punjab, Himachal Pradesh, Uttrakhand, West Bengal, Assam
				Degradation stages of Himalayan moist temperate forests [DS1-Montane bamboo brakes-*Arundinaria* spp.; DS2-Himalayan temperate parkland-*Prunus padus*; DS3- Himalayan temperate pastures-*Festuca* spp.]	Western to Eastern Himalayas
				General edaphic and seral types of Himalayan moist temperate forests [E1-Cypress forest-*Cypressus*	Uttrakhand, Punjab, Jammu

				torulosa; 1S1-Alder forest-*Alnus nitida*; 1S2-Riverain blue pine forest-*Pinus wallichiana*; 2S1-Low-level blue pine forest- *Pinus wallichiana*]	
	13-Himalayan Dry Temperate Forests (essentially open formations, along inner valleys of Himalaya, rainfall < 1000 mm, conifers like *Pinus* (e.g., *P. gerardiana*), *Picea* and *Juniperus*, predominate)	0.2	0.2	(i) *Western types* [C1-Dry broadleaved and coniferous forest (*Quercus ilex-Pinus gerardiana*); C2-Dry temperate coniferous forest: (2a) *Neoza* pine forest (*Pinus gerardiana*), (2b) Dry deodar forest-*Cedrus deodara*; DS1-*Pohu* scrub-*Parrotia jacquemontiana*; DS2-Dry temperate scrub-*Plectranthus rugosus*; C3-(West Himalayan dry temperate deciduous forest)-*Corylus colurna*; C4-West Himalayan high-level dry blue pine forest-*Pinus wallichiana*; C5-West Himalayan dry juniper forest (*Juniperus macropoda*)]	Jammu and Kashmir, Punjab, Himachal Pradesh, Uttrakhand
				(ii) *Eastern types* [C6-East Himalayan dry temperate coniferous forest-*Picea spinulosa*; E1-Larch forest-*Larix griffithiana*; C7-East Himalayan dry juniper/ birch forest-*Juniperus wallichiana*]	Sikkim
				General seral types of dry temperate forests [1S1-*Hippophae/Myricaria* scrub-*Hippophae salicifolia*; 1S2-*Populus/Salix* forest-*Populus euphratica*; 1S3-(Western high-level dry blue pine forest)-*Pinus wallichiana*]	Western to Eastern Himalayas
V-SUB-ALPINE FORESTS	14-Sub-Alpine Forests (stunted deciduous or evergreen forests with conifers (2900-3500m altitude), mean annual temp. 2ºC, rainfall 83-600 mm, species of *Abies*, *Betula* and *Rhododendron* predominate)	-	-	[C1-West-Himalayan sub-alpine birch/fir forests (*Betula/Abies*): (1a) West Himalayan sub-alpine fir forest-*Abies spectabilis*, (1b) West Himalayan sub-alpine birch/fir forest-*Betula utilis*; C2-East Himalayan sub-alpine birch/fir forest-*Abies densa*]	Jammu and Kashmir, Punjab, Himachal Pradesh, Uttrakhand, Bengal, Assam, Manipur
				Seral and degraded types of sub-alpine forests [1S1-(*Hippophae/Myricaria* brakes)-*Hippophae salicifolia*; 1S2-(Deciduous sub-alpine scrub)-*Syringa emodi*; 2S1-(Sub-alpine blue pine-*Pinus wallichiana* forest); DS1-Sub-alpine pastures-*Agropyron longearistatum*]	Jammu & Kashmir, Punjab, Himachal Pradesh, Uttrakhand, Bengal, Assam, Manipur
VI-ALPINE SCRUB	15-Moist-Alpine Scrub (throughout Himalaya, above timber line to 5500 m altitude, species of *Juniperus, Rhodo-dendron* predominate)	3.3	4.3	[C1-Birch/*Rhododendron* scrub forest-*Betula utilis*; C2-Deciduous alpine scrub-*Syringa emodi*; E1-Dwarf *Rhododendron* scrub- *Rhododendron campanulatum*; E2-(Dwarf juniper scrub)-*Juniperus communis*; C3-(Alpine pastures)-*Primula* spp.]	Jammu & Kashmir, Uttrakhand, Sikkim, Manipur
	16-Dry-Alpine Scrub (in low rainfall areas, upto 5500 m altitude, as xerophytic, e.g., *Juniperus, Eurotia, Salix*, etc.)	-	-	[C1-Dry alpine scrub-*Eurotia ceratoides*; E1-Dwarf juniper scrub-*Juniperus communis*]	Uttrakhand, Punjab, Himachal Pradesh, Jammu & Kashmir,

*Dominant species

smaller, broad-leaved with dense leaf canopy, abundant epiphytic flora and rich herbaceous undergrowth; Shola forests belong to this category, (ii) Himalayan moist forests comprise tall (up to 45 m high) conifers, oaks or their mixture with thin partly deciduous undergrowth; (iii) Himalayan dry forests are essentially open formations and occur in the inner ranges of Himalaya with very low rainfall. These forests are characterized by the dominance of evergreen oaks and conifers. Undergrowth is formed by scrubs. The group has a western (characteristic species *Pinus gerardiana*) and an eastern counterpart (characteristic species *Picea spinulosa*); both types have an abundance of Junipers.

Sub-alpine forests occur in the Himalaya and

Table 5: Tropical dry deciduous forest categories of India (based on Champion and Seth, 1968).

Southern tropical dry deciduous forests		Northern tropical dry deciduous forests
Dry teak bearing forest		Dry sal-bearing forest
Dry teak forest		Dry Siwalik sal forest
Very dry teak forest		Dry plains sal forest
Dry red sanders bearing forest		Dry peninsular sal forest
Southern dry mixed deciduous forest		Northern dry mixed deciduous forest
Degradation stages	Edaphic types	Seral types
Dry deciduous scrub	*Anogeissus pendula* forest	Dry tropical riverain forest
Dry savannah forest	*Anogeissus pendula* scrub	Khair (*Acacia catechu*)-sissoo (*Dalbergia sissoo*) forest
Dry grassland	*Boswellia* forest	Inundation babul (*Acacia nilotica*) forest
Euphorbia scrub	Babul (*Acacia nilotica*) forest *Hardwickia* forest *Butea* forest *Aegle* forest, Laterite thorn forest, Saline/alkaline scrub savannah, *Phoenix* savannah, Babul (*Acacia nilotica*) savannah, *Salvadora-Tamarix* scrub, Dry bamboo brake	Secondary dry deciduous forest

Degradation stages, and edaphic and seral types occur in both southern and northern areas

experience extremely low temperature and humidity. These are stunted deciduous or evergreen forests with conifers. The alpine scrub vegetation comprises (i) moist-alpine scrub dominated by dwarf, evergreen shrubby conifers and broad-leaved species along with a prominent shrub layer; (ii) dry-alpine scrub comprising open formation of xerophytic scrubs with many herbs and grasses.

The Himalayan vegetation was divided into 11 forest formations by Singh and Singh (1987) on the basis of leaf characters (leaf drop pattern, leaf size, texture and shape), and elevation (Fig. 5 and Table 6). These authors have avoided using the term 'alpine', because they feel that the 'alpine' conditions in the Himalaya are not analogous to those of the Alps. The categories recognized by Champion and Seth (1968) that fall within the 11 formation types of Singh and Singh (1987) are also indicated in Table 6 and briefly described below.

Among the 11 forest formations, the submontane broadleaf ombrophilous forest has high species richness, multistratal structure, and abundance of buttressed trees 50 m or more tall. The common genera in this forest are *Dipterocarpus*, *Artocarpus*, *Syzygium, Mesua*, and *Myristica*. In the submontane seasonal broadleaf forest, about 60-90% of the top canopy is represented by *Shorea robusta*,which is the most extensively distributed and dominant species.

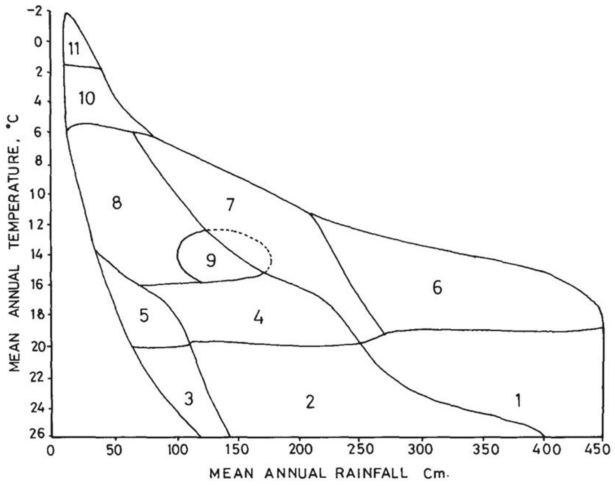

Fig. 5: Forest formations of the Himalaya in relation to rainfall and temperature. 1, Submontane broadleaf ombrophilous forest; 2, Submontane seasonal broadleaf forest; 3, Submontane broadleaf summer deciduous forest; 4, Low-montane needle-leaf forest with concentrated summer leaf-drop; 5, Low-montane sclerophyllous evergreen broadleaf forest; 6, Mid-montane broadleaf ombrophilous forest; 7, Low to mid-montane hemi-sclerophyllous broadleaf forest with concentrated summer leaf-drop; 8, Mid-montane needle-leaf evergreen forest; 9, Mid-montane winter deciduous forest; 10, High-montane mixed stunted forest; and 11, Very high-montane scrub (Source: Singh and Singh, 1987)

The common canopy associates of sal in this forest are *Schima wallichii, Stereospermum personatum*,

Table 6: Formation-types recognized in the Himalaya compared with the vegetation-types recognized by Champion and Seth (1968) (Source: Singh and Singh, 1987)

Formation-type	Equivalent groups, subgroups, and categories of Champion and Seth (1968)
Submontane broadleaf ombrophilous forest	Northern tropical wet evergreen forest (1B) and mesic part of northern tropical semi-evergreen forest (2B), lower part of northern subtropical broadleaved wet hill forest (8B)
Submontane seasonal broadleaf forest	Drier part of 2B and moist parts of the mixed deciduous forest ($3C/C_3$)
Submontane broadleaf summer-deciduous forest	Northern dry mixed deciduous forest ($5B/C_2$), and, dry Siwalik sal forest ($5B/C_{1a}$), moist mixed deciduous forest ($3C/C_3$)
Low-montane needle-leaf forest with concentrated summer leaf-drop	Subtropical pine forest (9)
Low-montane sclerophyllous evergreen broadleaf forest	Subtropical dry evergreen forest ($10C/C_1$)
Mid-montane broadleaf ombrophilous forest	East Himalayan wet temperate forest ($11B/C_1$), higher part of northern subtropical broadleaf wet hill forest (8B)
Low to mid-montane hemisclerophyllous broad-leaf forest with concentrated summer leaf-drop	Lower western Himalayan temperate forest ($12/C_1$) and upper west Himalayan temperate forest ($12/C_2$), excluding coniferous categories and deciduous category
Mid-montane needle-leaf evergreen forest	Coniferous categories of lower western ($12/C_l$) and upper west ($12/C_2$) Himalayan temperate forests and east Himalayan moist temperate forest ($12/C_3$)
Mid-montane winter-deciduous forest	Moist temperate deciduous forest category of lower western Himalayan temperate forest ($12/C_{le}$)
High-montane mixed stunted forest	Subalpine forest (14)
Very high-montane scrub	Alpine scrub (15)

Sterculia spp., *Caschela microcarpa, Lagerstroemia parviflora, Terminalia* spp., *Machilus villosa,* and *Anogeissus latifolia*. In the submontane broadleaf summer deciduous forest, diversity is relatively high, and unlike the previous type, species dominance is not marked. In Bhabar of Kumaun Himalaya, *Albizia procera, Adina cordifolia, Terminalia tomentosa, T. bellerica, Toona ciliata,* and *Anogeissus latifolia* form the canopy, and *Mallotus philippensis* (a member of sal undercanopy) and *Ougeinia oogeinensis* form the understory tree layer. As recognized by Kenoyer (1921), a *Bauhinia* forest (common species, *B. retusa, B. variegata,* and *B. vahli*) with open canopy occur in the hills of Kumaun.

Low-montane needle-leaf forest with concentrated summer leaf drop formation type is represented by *Pinus kesiya* in Eastern Himalaya and *P. roxburghii* in Central and Western Himalaya. The shrub layer in this forest type is poor, and grasses predominate in the ground flora because of frequent burning (Saxena, 1979). Low-montane sclerophyllous evergreen broadleaf forest is dominated by *Olea cuspidata* and has abundant shrub layer. In the mid-montane broad leaf ombrophilous forest, none of the species generally attain more than 12% relative importance. Stratification is less developed and height of trees is lower. Common species are members of the Lauraceae, *Machilus edulis, Michelia cathertii, Magnolia* spp., *Quercus lamellosa, Q. serrata, Castanopsis* spp., *Acer campbelli,* etc. Low to mid-montane hemi-sclerophyllous broadleaf forest with concentrated summer leaf drop type is species poor, rich in epiphytes, and generally has closed canopy (more than 80%). Herb layer is less developed, without grasses, while the shrub growth is conspicuous. Due to predominance of generally one or two species, the dominant types are easily recognizable: (i) *Quercus leucotrichophora* (banj oak) forest, (ii) *Q. lanuginosa* (rianj oak) forest, (iii) *Q. floribunda* (tilonj oak) forest, (iv) *Q. semecarpifolia* (kharsu oak) forest, and (v) *Q. leucotrichophora-Q, floribunda* forest. These dominant types exhibit a remarkable feature of altitudinal variation in oak species.

Mid-montane needle-leaf evergreen forest is mostly dominated by needle-leaved species, viz., *Cedrus deodara* (deodar) and *Pinus wallichiana*

(blue pine). Western part mostly contains *Abies pindrow* (silver fir) and *Picea smithiana* (spruce), and the eastern part has *Abies delavayi*, *A. hylium*, and *Tsuga dumosa* (hemlock) among the dominants. Mid-montane winter deciduous forest occurs in the region occupied by mid-montane hemi-sclerophyllous and needle-leaf evergreen forests. This forest type generally occupies the moist places of limited areas along the streams. The common species are *Aesculus indica, Acer pictum, A. caesium, Carpinus viminea, Ulmus wallichiana, Betula alnoides, Pyrus lanata, Juglans regia*, and *Fraxinus micrantha*. In the high-montane mixed stunted forest (above 3000 m), plants mainly depend on snowmelt for their water requirement, as the effect of monsoon is minimum. In the central and western Himalaya, the common species are deciduous birch or bhojpatra (*Betula utilis*), evergreen fir (*Abies spectabilis*), evergreen oak (*Q. semecarpifolia*). In the lower canopy, *Rhododendron campanulatum* (3-10 m) is the most common species. In the last formation type, i.e., very high-montane scrub (above 3500 m and up to 4900 m), all taxa of the above mentioned formations are present except for the *Abies* species. The common herbaceous associates in this type are species of *Caragana* and *Artemisia*.

Grassland Ecosystems

The grassland ecosystems in many parts of India have originated due to destruction of natural forests by biotic interference, particularly due to excessive grazing and land clearing for agriculture (http://environmentofearth.wordpress.com/tag/vegetation). Dabadghao and Shankarnarayan (1973) identified five major grass cover types (Table 7). According to Whyte (1968), the distribution of these grass cover types is primarily governed by climatic factors, and chiefly by latitude. Thus, while *Sehima-Dichanthium* cover is tropical, the *Dichanthium-Cenchrus-Lasiurus, Phragmites-Saccharum-Imperata* and *Themeda-Arundinella* covers are distinctly sub-tropical. The temperate-alpine cover is distinct from the above types. The altitude separates the *Themeda-Arundinella* grass cover which is restricted to the northern hills from *Phragmites-Saccharum-Imperata* and from *Dichanthium-Cenchrus-Lasiurus* types which occur in plains. In the plains, moisture conditions separate *Phragmites-Saccharum-Imperata* type (moist to wet habitats) from the *Dichanthium-Cenchrus-Lasiurus* type (relatively dry habitats).

Whyte (1968) has also maintained a Nilgiri high-altitude grass cover type dominated by *Andropogon polyptychus* and *Chrysopogon zeylanicus* which represents a sub-climax stabilized by fire, grazing and erosion.

The areas occupied by the five grass cover types as shown by Dabadghao and Shankarnarayan (1973) represent the potential area; however, much of the area shown under each grass cover type is presently either under forest or under cultivation (Yadava and Singh, 1977). Further, due to local variations in climate, topography, soil and biotic pressure, a myriad of distinct or transitional communities occur within the potential area of each of the above major grassland types (Yadava and Singh, 1977; Singh and Gupta, 1993).

Wetland Ecosystems

The inland aquatic ecosystems are also very diverse and include rivers, streams, springs, lakes, lagoons, estuaries and various human made habitats as rivers, canals, tanks/ponds (Gopal, 2013). The country is covered by a network of 14 major, 44 medium and several minor rivers and their tributaries (Rao, 1975). Natural lakes are few and cover about 0.72 million ha (Jhingran, 1991), but > 4290 large and numerous smaller reservoirs cover more than 3.15 million hectares (Sugunan, 1995; Suryanarayanan, 1996). These water bodies are supplemented by thousands of temple tanks, oxbow lakes and village ponds. Jhingran (1991) estimates 1.81 million ha of oxbow lakes and 2.75 million ha peninsular tanks. Other floodplain and seasonal shallow water habitats may account for another 1.5 million ha. The coastal mangroves (0.4 million ha), estuaries (3.9 million ha) and lagoons and backwaters (3.5 million ha) lying inland (behind coastline) account for further 8 million ha; thus, the total area of inland aquatic ecosystems (excluding cultivated paddy fields) is estimated at about 18 million ha (Gopal, 1997).

Depending upon the duration of water logging, Gopal (1987) has grouped Indian fresh water wetlands into two major types: (i) the perennial wetlands, with water logging throughout the year, include habitats such as river banks and margins of large lakes or reservoirs, and (ii) seasonal wetlands which dry up

Table 7: Major grassland types of India (based on Dabadghao and Shankarnarayan, 1973)

Grassland types	Characteristics	Occurrence
Sehima-Dichanthium	topography undulating, rainfall 300-6350 mm; develop on sandy-loam soils; dominant component comprises 24 perennial grasses along with 129 herbaceous species including 56 legumes; on gravelly soils and under protection or light grazing *Sehima* dominates and on level soils *Dichanthium* is the dominant grass	peninsular India including the central Indian plateau, Chhota Nagpur plateau and the Aravalli ranges
Dichanthium-Cenchrus-Lasiurus	topography broken here and there by spurs of southern hill ranges and by sand dunes in western Rajasthan, monsoon rainfall 100-700 mm; eleven important perennial grasses with 45 herbaceous species including 19 legumes; *Cenchurus setigerus* and *C. cilliaris* from communities where soil is not too dry, and *Lasiurus indicus* on loose sandy soil in areas receiving less than 300 mm rainfall	northern portion of Gujarat, whole of Rajasthan, western Uttar Pradesh and Punjab
Phragmites-Saccharum-Imperata	topography level characterized by low-lying, ill-drained soils; 19 principal grass species and 56 herbs including 16 legumes predominate	part of Gangetic plains, the Brahmaputra valley and extends to the plains of Punjab
Themida-Arundinella	rainfall 1000-2000 mm, snow-fall in winter towards upper ranges; 16 perennial grasses (including species of *Bothriochloa*, *Chrysopogon* and *Cymbopogon*) and 34 herbaceous species including 9 legumes, are important constituents	appears around the altitude 350 m and extends upto 2100 m
Temperate-Alpine	35 important perennial grasses (including species of *Agrostis*, *Danthonia*, *Phleum* and *Poa*), 68 herbaceous species including 6 legumes are important vegetation components	occurs above 2100 m in northern montane belt and above 1500 m in the eastern belt, snow-fall is common

completely for varying periods of time depending upon the vagaries of monsoon, examples are numerous village ponds, fish ponds, paddy fields, river flood plains, etc. Biswas (1984) has reported 1193 wetlands in India covering a total area of 3.9 million hectares in 274 districts of India.

The aquatic ecosystems including wetlands support diverse communities which harbour about 1800 algal species and 1250 higher plant species (Gopal, 2013). The aquatic (and wetland) flora (including algae) constitute more than 15% of the India's total estimated floristic diversity (Gopal, 1997). The aquatic faunal component is also prominent. According to Gopal (2013), there are about 300 Rotifera, 285 Mollusca, 100 Cladocera, 100 Ostracoda, > 300 Copepoda, 742 fishes, and about 1000 Aves. The species diversity of fishes, birds and other fauna is very high in many aquatic habitats. For example, there are more than 330 species of birds but fewer species of fishes in Keoladev National Park (Vijayan, 1995), 64 fish species and 116 species of birds in Loktak lake (Singh and Singh, 1994), and 217 fish and 160 bird species in Lake Chilika (Ram *et al.*, 1994).

Mangrove Ecosystems

The term mangrove refers to an ecological group of halophytic plant species as well as to a variety of complex plant communities dominated by these species (Upadhyay *et al.*, 2002).The coastal zone of the mainland of India and that of Andaman and Nicobar Islands is endowed with the presence of extensive and diverse mangroves (MoEF, 2009). About 5% of the world's mangrove vegetation at the global level has been reported from India which accounts for 0.67% of the total designated forest area of the country and is spread over an area of 4,662.56 km^2 along the coastal States/UTs (Das Gupta and Shaw, 2013). Over the past two decades (1987 to 2011), the mangrove forest cover has increased by 616.56 km^2 (FSI, 2016). The very dense mangrove comprises 1403 km^2 (30.10% of the mangrove cover), moderately dense mangrove is 1658.12 km^2 (35.57% of the mangrove cover) while open mangroves cover an area of 1600.44 km^2 (34.33% of the mangrove cover) (MoEF, 2012). West Bengal has the maximum of mangrove cover in the country, followed by Gujarat and Andaman and Nicobar Islands.

Mangrove ecosystems are among the most productive and biologically diverse ecosystems and

constitute a bridge between terrestrial and marine ecosystems (MoEF, 2012). The dominant salt-tolerant, sclerophyllous broadleaved trees form a unique ecosystem with associated plants, including epiphytic and terrestrial ferns, orchids, lichens, non-mangrove halophytes, sea grasses and seaweeds, and fauna such as fish, shrimp, shellfish, crabs, lobsters, reptiles and birds (Upadhyay *et al.*, 2002). These ecosystems are found in the inter-tidal zones of sheltered shores, estuaries, creeks, backwaters, lagoons, marshes and mud-flats. Mangroves provide habitats, spawning grounds, nurseries and nutrients to a number of animals (MoEF, 2009) and harbour several endangered species ranging from reptiles (e.g. crocodiles, iguanas and snakes) and amphibians, to mammals (tigers, deer, otters and dolphins) and birds (herons, egrets, pelicans and eagles). One hundred and sixteen plant species have been recorded which include 59 mangrove species, 47 algae and 10 species of sea grasses (Banerjee *et al.*, 1989). About 65 vascular plant species belonging to 31 families and 59 genera have been reported from the mangrove ecosystems of India (Banerjee and Ghosh, 1998). Faunal diversity in mangrove forests of India is also immense, for example, number of species of Crustaceans 229, Molluscs 212, Wood borers 25, Fishes 185, Reptiles 39, Birds 117, Mammals 36 , Microbenthos 111, Shellfishes 20 (Jagtap, 1994).

The number and dominant species of major mangrove wetlands of India are shown in Table 8.

Marine and Coastal Ecosystems

As elsewhere in the world, the extent of marine biodiversity in India is relatively less known (MoEF, 2009). More than 13,000 coastal and marine species have been reported from India. The total area of coral reefs comprises 2,375 sq km (Ministry of Earth Sciences and Space Application Centre, 1997). Major coral reef ecosystems are in Gulf of Mannar, Gulf of Kachchh, Andaman and Nicobar, and Lakshadweep Islands and embrace all the three major reef types (atoll, fringing and barrier) (MoEF, 2009).

According to India's fourth National Report to the Convention on Biological Diversity (CBD) (MoEF, 2009), the Andaman Islands have around 80% of the global coral diversity, suggesting that a final count could reach up to 400 species. These include 15 families, 60 genera and 208 species of *Scleractinia* (reef building and hermatypic corals) from four major reefs of India viz., Gulf of Kachchh (36 species, 20 genera) Lakshadweep (91 species, 34 genera), Gulf of Mannar and Palk Bay (82 species 27 genera) Andaman and Nicobar Islands (177 species, 57 genera).

Agro-Ecosystems

India has a variety of distinct agro-ecosystems, characterized by variations in edaphic, climatic and geographic features, and consequently a diverse cropping pattern and crop composition. The country is one of the eight Vavilov's centers of origin of

Table 8: Characteristics of major mangrove wetlands of India (Source: Selvam, 2003)

Mangrove	Total rainfall (mm)	No. of species	Dominant species
East coast of India			
Sunderbans	1600 to 1800	26	*Excoecaria agallacha*, *Ceriops decandra* and *Sonneratia apetala*
Mahanadi	1600	26	*Excoecaria agallacha*, *Ceriops decandra* and *Sonneratia apetala*
Godavari	1100	17	*Excoecaria agallacha*, *Avicennia officinalis* and *Sonneratia apetala*
Krishna	1200	12	*Avicennia marina*
Pichavaram and Muthupet	1300	11	*Avicennia marina*
West coast of India			
Gulf of India	470	8	*Avicennia marina*
Gulf of Khambat	900	8	*Avicennia marina*
Andaman and Nicobar Islands	2750 to 3080	24	*Rhizophora apiculata*, *Rhizophora mucronata* and *Ceriops tagal*

cultivated plants in the world. India has more than 800 crop species, each with immense variation, for example rice has 50,000 varieties and sorghum 5,000 varieties. Needless to say, a wide variety of weeds make a part of the agro-ecosystems. The National Bureau of Soil Survey and Land Use Planning distinguished 20 broad agro ecological zones, based on natural features and growing periods (Table 9). This large variety of ecological zones signifies the distinct agro-ecosystems.

No discussion on agro-ecosystems can ignore the shifting or slash and burn agriculture, so predominant in the northern India. Shifting cultivation is one of the oldest farming systems, believed to have originated in the Neolithic period around 7000 B.C., and is still practiced in the states of Andhra Pradesh, Nagaland, Meghalaya, Mizoram, Manipur, Tripura, Arunachal Pradesh, Kerala, Karnataka and Orissa, by about 5 million tribal families on 4.37 mha. Shifting cultivation consists of clearing a plot of forest land by burning the vegetation and cultivating for one or two years. Subsequently, the old cultivated plot is left fallow for a variable period of time, to allow for the recovery of the vegetation, and then again it is cleared by burning and cultivated. The practice has been extensively documented (see Ramakrishnan, 1992; Ramakrishnan, 2015; Ranjan and Upadhyay, 1999; Shillong Declaration, 2004; Tiwari, 2007; Deb *et al.*, 2013). Because of the increasing population and increasing demand for land for cultivation, the fallow period has declined from 25-30 years to 2-3 years. This has resulted in large-scale deforestation, soil and nutrient loss, and invasion by weeds and other species (see Ranjan and Upadhyay, 1999, Deb *et al.*, 2013, Ramakrishnan, 2015). The shifting cultivation practices vary from tribe to tribe in terms of land tenure, fallow period, species cultivated and innovations. Table10 gives an example of three tribes in Meghalaya.

Human Impacts

The growing human population has exerted a significant impact on all ecosystem types in all regions of India. High human and livestock demand for food, fodder and firewood has resulted in overexploitation of terrestrial as well as aquatic ecosystems. Wind and water erosion, water logging and problems of salinity and alkalinity have resulted into land degradation of at least one third of the geographical area. Human activities have also resulted into high air and water pollution. India now has 321 globally threatened floral and 614 faunal species as per the IUCN (2012) Red List.

There has been a conspicuous change in land-use pattern, habitat loss and forest fragmentation. For example, Jha *et al.* (2005) observed in the Vindhyan dry tropical forest an increase in number of patches formed due to forest fragmentation with corresponding decrease in mean patch area and mean patch perimeter during a ten year period. The large forest fragments contained the greatest number of tree species. Sagar and Singh (2004) have reported that about 52% of the total 65 species inventoried in a dry tropical forest, exhibited local demographic instability. The increase in the proportion of declining species with increase in disturbance intensity indicated that local anthropogenic pressure was responsible for the depression. Sagar and Singh (2005) observed a conspicuous decline in species richness and alpha diversity due to biotic disturbance in the forest (Fig. 6) Chaturvedi *et al*. (2017b). Large tracks of natural forests have been converted into cultivated land or monoculture of cash and timber crops such as tea, coffee, rubber, teak and eucalyptus.

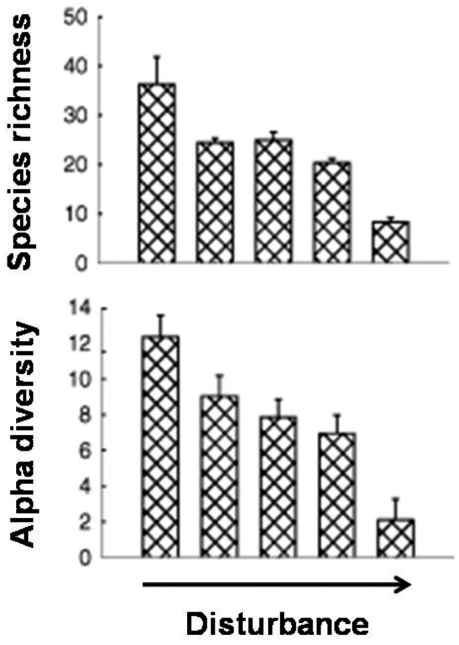

Fig. 6: Species richness and alpha diversity in a gradient of disturbance (from least to highest) in the dry tropical forest region (Source: Sagar and Singh, 2005)

Table 9: Agro-ecological regions in India

Agro-ecological regions	Descriptive features	Major crops
Arid Ecosystem		
Western Himalayas (Eastern and Western aspect of Ladakh Plateau, north Kashmir Himalayas)	cold, hyper-arid; shallow skeletal soils; length of Growing Period (GP) <90 days	millets, barley and wheat
Western Plain, Kachchh and part of Kathiawar Peninsula (Rajasthan Bagar, North Gujarat Plain and South-Western Punjab Plain, Kachchh and North Kathiawar Peninsula)	hot, hyper-arid; desert and saline soils; GP <90 days	millets and pulses
Deccan plateau (Karnataka Plateau)	hot arid; red and black soils; GP <90 days	millets, cotton and oil seeds
Semi-arid Ecosystem		
Northern Plain (and Central Highlands) including Aravallis (North Punjab Plain, Ganga-Yamuna Doab and Rajasthan Upland, North Gujarat Plain, Rohilkhand and Avadah Plain, Madhya Bharat Plateau and Bundelkhand Uplands)	hot dry/moist semi-arid; alluvium derived soils; GP 90-150 days	millets, wheat, pulses, maize, sugarcane and cotton
Central (Malwa) Highlands, Gujarat plains and Kathiawar Peninsula (Coastal and Central Kathiawar Peninsula, Madhya Bharat Plateau, Western Malwa Plateau, Eastern Gujarat Plain, Vindhyan and Satpura range and Narmada Valley)	hot dry/moist semi-arid; medium and deep black soils; GP 90-150 days	millets, wheat and pulses
Deccan Plateau (Central, Eastern and Western Maharashtra Plateau, North and Western Karnataka Plateau, North Western Telangana Plateau, North Sahyadris)	hot dry/moist semi-arid, hot sub-humid; shallow and medium (with inclusion of deep) black soils; GP 90-150 days	millets, cotton, pulses and sugarcane
Deccan Plateau (Telangana) and Eastern Ghats (North and South Telangana Plateau, Eastern Ghat)	hot dry/moist semi-arid/dry sub-humid; red and black soils; GP 90-150 days	millets, oilseeds, rice, cotton and sugarcane
Eastern Ghats and Tamil Nadu Uplands and Deccan (Karnataka) Plateau (Tamil Nadu Uplands and Plains, Leeward Flanks of South Sahyadris, Central Karnataka Plateau)	hot dry/moist semi-arid; red loamy soils; GP 90-150 days	oilseeds, rice, cotton and sugarcane
Sub-humid Ecosystem		
Northern Plain (Punjab, Rohilkhand, Avadh and south Bihar Plains)	hot dry/moist sub-humid; alluvium-derived soils; GP 150-180 days	pulses and sugarcane
Central Highlands (Malwa and Bundelkhand) (Malwa Plateau, Vindhyan Scarpland and Narmada Valley, Satpura range and Eastern Maharashtra Plateau, Bundelkhand Plateau, Wainganga Valley)	hot dry/moist sub-humid; black and red soils; GP 150-180 (to 210) days	sorghum and pulses
Chhattisgarh/Mahanadi Basin (Chhattisgarh/Mahanadi Basin)	hot dry/moist sub-humid; red and yellow soils; GP 150-180 days	rice, millets and wheat
Eastern Plateau (Chhotanagpur) and Eastern Ghats (Garjat Hills, Dandakaranya and Eastern Ghats, Chhotanagpur Plateau)	hot dry/moist sub-humid; red and lateritic soils; GP 150-180 (to 210) days	rice, pulses and millets
Eastern Plain (North Bihar and Avadh Plains, Foothills of Central Himalayas)	hot/warm dry/moist sub-humid; alluvium-derived soils; GP 180-210 days	rice, wheat and sugarcane
Western Himalayas (South Kashmir, Himachal Pradesh, Punjab and Kumaun Himalayas)	cold and warm by dry semi-arid/dry sub-humid, warm moist sub-humid; brown forest and podzolic soils; GP 180-210 + days	wheat, millets, maize and rice
Humid-perhumid Ecosystem		
Assam and Bengal Plain (Middle, Lower and Upper Brahmaputra Plain, Bengal basin, North Bihar Plain, Teesta, Barak Valley)	hot/warm moist sub-humid/ humid; alluvium-derived soils; GP 210 + days	rice, jute and plantation crops

Eastern Himalayas (Bhutan foot-hills, Darjeeling and Sikkim Himalayas, Arunachal Pradesh, Manipur, Mizoram, Tripura)	warm to hot per-humid; brown and red hill soils; GP 210 + days	rice and millets
North-eastern Hills (Purvachal) (Meghalaya Plateau, Nagaland Hill, Purvachal)	warm to hot moist humid to per-humid; red and lateritic soils; GP 210 + days	forest and rice in patches
Coastal Ecosystem		
Eastern Coastal Plain (South and North Tamil Nadu Plains (Coastal), Andhra Plain, Utkal Plain, East Godavari Delta, Gangetic Delta)	hot dry/moist semi-arid/sub-humid/ humid; coastal alluvium-derived soils; GP 90-210 + days	rice, pulses and millets
Western Ghats and Coastal Plain (Central, North and South Sahyadris and Konkan Coast, Karnataka and Kerala Coastal plain)	hot moist sub-humid to humid; red, lateritic and alluvium- derived soils; GP 219 + days	rice, tapioca, coconut and millets
Island Ecosystem		
Islands of Andaman-Nicobar and Lakshadweep (Andaman and Nicobar group of Islands, Level Lakshadweep and group of Island)	hot per-humid/humid; red loamy and sandy soils; GP 210 + days	forest, coconut and rice

River systems have been greatly affected by building dams and reservoirs. A study in the Himalayan region (Pandit and Grumbine, 2012) has reported that the ongoing and proposed hydropower development would adversely affect the persistence of species across the taxonomic groups. The study emphasized that the proposed dam building would affect nearly 90% of Indian Himalayan valleys, and by 2025, about 22 angiosperm and 7 vertebrate taxa might become extinct. Due to disturbance in the dense forests caused by dam building, a reduction of 35% tree species richness, 42% tree density, and 30% tree basal cover is expected in the Himalayan region (Pandit and Grumbine, 2012).

The wetland ecosystems are threatened by discharge of waste effluents, surface runoff, weed infestation and uncontrolled siltation. Overfishing has resulted into a decline of fishery resources of fresh and marine water bodies. Changes in temperature, precipitation, evapo-transpiration and run-off have been suggested to alter the hydrological regime of the inland natural wetlands, particularly in arid and semi-arid regions (Patel *et al.,* 2009). Few studies have reported that some of the most sensitive high altitude and coastal wetlands of India including mangroves and coral reefs are likely to be affected by climate change (Patel *et al.,* 2009). It has been estimated that the climate change induced sea level rise of 1m could result in the loss of 84% of coastal wetlands and 13% of saline wetlands of India (Blankespoor *et al.,* 2012; Bassi *et al.,* 2014).

On account of anthropogenic factors (reclamation of land, discharge of wastes, etc.) and natural factors like global warming, mangrove ecosystems are presently one of the most threatened ecosystems (MoEF, 2012). Due to diversion of freshwater in the upstream area, the periodicity and quantity of freshwater reaching the mangrove environment has been reduced leading to a dramatic change in the floral diversity of the mangrove wetlands (Selvam, 2003). Some of the mangrove species are on the way to extinction from the west coast, examples are *Xylocarpus granatum*, *Bruguiera cylindrica*, *Sonneratia acida* and *Cynometra ramiflora*. Similarly, *Nypa fruticans*, *Heritiera minor* and *H. formes* have all but disappeared from the Sunderbans (Upadhyay *et al.,* 2002). The current status of all mangrove wetlands in India, except those of Andaman and Nicobar islands, indicates that the species having low-saline tolerance are gradually disappearing and the species like *Avicennia marina* exhibiting broad range of salinity tolerance are becoming dominant (Selvam, 2003).

The disturbance of terrestrial ecosystems has seen the spread of invasive alien species degrading the health of natural as well as manmade ecosystems. Biotic invasions interfere with the socio-economic system, food security, human and animal health and cause enormous harm of the region (Kohli *et al.,* 2012). Other environmental problems such as landscape change, disturbance and climate change further increase the biotic invasion process (Kohli *et al.,* 2012). In the north-eastern hill region of India,

Table 10: Salient features of Shifting cultivation practiced by Khasi, Karbi and Garo communities of Meghalaya (Source: Deb *et al.*, 2013)

Activities	Name of the tribes		
	Khasi	Karbi	Garo
Land ownership	Private/Rented	Private	Community
Allotment of plot by traditional institution	Not necessary	Not necessary	Practiced
Labour for slashing and burning	Family members	Family members	Community activity
Burning Months	February-March	April	March
Sowing Months	March-May	April-June	March-April
No. of crops grown	14-16	24	30-35
Dominant subsistence crops	Bean, Bitter gourd, Coix (Sohriew), Cucumber, Soyabean, Dioscorea, Pea, Raddish, Potato, Sweet Tapioca and etc.	Bean, Bitter gourd, Cucumber, Jhika (fruit), Lady's finger, Lao, Maize, Mesta, Sponge gourd, Banana, Paddy, Sweet Potato, Tapioca and Turmeric	Brinjal, Lai sak (leaf), Local lettuce, Millet, mustard, Sesame, Bean, Bilik (legume), Cotton, Cucumber, Gourd, Kharek (fruit), Jingka (fruit), Lady's finger, Lau, Lentil, Melon, Mesta, Paddy, Cauliflower Pumpkin
Cash crops	Turmeric, Potato, Maize, Colocassia	Potato, Colocassia, Pumpkin, Chilly, Ginger	Ginger, Maize, Chilly, Pumpkin
Fruit trees	*Artocarpus chaplasha*, *Citrus* sp., *Litchi chinensis, Mangifera indica, Myrica esculenta, Prunus nepalensis, Musa* sp.	*Artocarpus* sp.	*Musa* sp., *Citrus* sp.
Fuel wood trees	*Artocarpus* sp., *Betula alnoides, Castanopsis tribuloides, Ficus bengalensis, Litchi chinensis, Mallotus nepalensis, Mangifera - indica, Myrica esculenta, Prunus nepalensis, Quercus* sp. and *Schima wallichi*	*Albizia procera, Artocarpus* sp., *Cassia fistula, Duabanga grandi-flora,Gmelina arborea, Michelia champaca, Shorea robusta, Tectona grandis* and *Toona ciliata*	*Actinodaphne obovata, Albizia chinensis, Albizia odoratissima, Callicarpa arborea, Careya arborea, Duabanga grandiflora, Eurya japonica, Gmelina arborea, Macaranga* sp. and *Trema orientalis*
Weeding	Twice	Once	Twice
Harvesting period	June-July, Nov-Jan	June-Feb	June-Feb
Cropping period (years)	1	1	1-3
Fallow period (years)	8-15	3-5	7-9
Production (kg ha^{-1})	4653	1991	11293

Kushwaha *et al*. (1981) observed that due to increased population pressure and reduction in the availability of cultivation land, people have reduced the fallow period in the shifting agriculture to about 4-5 years, which has led to enormous increase in the population of noxious weeds like *Chromolaena odorata*. In India, about 18% flora is composed of adventive aliens, which have caused havoc in the terrestrial and aquatic ecosystems (Raghubanshi *et al*., 2005). Important invasive plants in India are listed in Table 11.

Ecosystem Conservation Scenario

India has taken significant steps for conservation of its biodiversity. We have a network of 683 Proctected areas for *in-situ* conservation (National Parks 102, Wildlife Sanctuaries 520, Conservation Reserves 57 and Community Reserves 4, established under the Wildlife (Protection) Act, 1972) covering a total area of 164980.75 km^2 (5.02% of the total geographical area of the country) (http://wiienvis.nic.in/Database/Protected_Area_854.aspx). India also has special

Table 11: List of Prominent Invasive Alien Plants in Indian Subcontinent (Arranged as per alphabetic order of family) (Source: Kohli *et al.*, 2012)

S.No.	Family name	Botanical and (Common name in parentheses)	Nativity	Life-form
1.	Amaranthaceae	*Chenopodium album* (Lamb's-quarters)	Europe	Herb
		Alternanthera philoxeroides (Alligator weed)	South America	Aquatic herb
2.	Amaryllidaceae	*Zephyranthes citrina* (Yellow rain lily)	Cent. South America	Herb
3.	Apocynaceae	*Cryptostegia grandiflora* (Rubber vine)	Madagascar	Vine-climber
4.	Araceae	*Pistia stratiotes* (Tropical duckweed)	South America	Aquatic Plant
5.	Asparagaceae	*Asparagus densiflorus* (Asparagus fern)	South Africa	Herb
6.	Asteraceae	*Ageratum conyzoides* (Billy goat weed)	Tropical America	Herb
		Ageratum houstonianum (Flossflower, Bluemink)	Central America, Mexico	Herb
		Ambrosia artemisiifolia (Small ragweed)	USA, Canada, Mexico	Herb
		Anthemis cotula (Stinking mayweed)	Europe	Herb
		Chromolaena odoratum (Siam weed)	Cent. South America	Shrub
		Cirsium arvense (Creeping thistle)	Europe	Herb
		Eupatorium adenophorum (Crofton weed)	Central America	Shrub
		Eupatorium cannabinum (Hemp-Agrimony)	British Isles	Herb
		Gymnocoronis spilanthoides (Senegal tea plant)	South America	Aquaticplant
		Leucanthemum vulgare (Oxe-eye daisy)	Europe	Herb
		Mikania micrantha (Mile-a-minute weed)	Cent. South America	Vine/Climber
		Parthenium hysterophorus (Ragweed parthenium)	Tropical America	Herb
		Sphagneticola trilobata (Singapore daisy)	Central America	Herb
		Synedrella vialis (Straggler daisy)	South America	Herb
		Tagetes minuta (Mexican marigold)	South America	Herb
7.	Azollaceae	*Azolla pinnata* (Mosquito fern)	Not Specific	Aquatic plant
8.	Bignoniaceae	*Macfadyena unguis-cati* (Cat's claw vine)	Central America	Climber
9.	Cabombaceae	*Cabomba caroliniana* (Green cabomba)	South America	Aquatic plant
10.	Convolvulaceae	*Ipomoea aquatica* (Water spinach)	China	Climber
		Merremia peltata (Merremia)	Africa	Climber
11.	Elaeagnaceae	*Elaeagnus umbellate* (Japanese Silverberry)	China, Korea, Japan	Tree/Shrub
12.	Euphorbiaceae	*Ricinus communis* (Castor bean)	Northeastern Africa	Tree/Shrub
		Sapium sebiferum (Chinese tallow)	China	Tree
13.	Fabaceae	*Acacia farnesiana* (Sweet acacia)	Tropical America	Tree/Shrub
		Acacia mearnsii (Black wattle)	Australia	Tree
		Acacia melanoxylon (Blackwood acacia)	Australia	Tree
		Leucaena leucocephala (Wild tamarind)	Tropical America	Tree
		Mimosa diplotricha (Giant sensitive plant)	South America	Climber/Shrub
		Mimosa pudica (Touch-me-not)	South America	Herb
		Prosopis juliflora (Mesquite)	Cent. South America	Tree
		Ulex europeus (Gorse)	Europe	Tree
14.	Hydrocharitaceae	*Hydrilla verticillata* (Water thyme)	Asia, North Australia	Aquatic plant
15.	Limnocharitaceae	*Limnocharis flava* (Yellow velvetleaf)	South America	Aquatic plant
16.	Melastomataceae	*Clidemia hirta* (Koster's curse) *Miconia calvescens*	South America	Shrub
		(Velvet tree)	Tropical America	Tree
17.	Moraceae	*Broussonetia papyrifera* (Paper mulberry)	China	Tree

18.	Myrtaceae	*Eugenia uniflora* (Surinam cherry)	South America	Tree
		Psidium guajava (Apple guava)	Cent. South America	Tree
19.	Onograneaceae	*Ludwigia peruviana* (Peruvian primerose willow)	South America	Aquatic plant
20.	Poaceae	*Arundo donax* (Giant cane)	Indian subcontinent	Grass
		Imperata cylindrica (Cogon grass)	Asia/Africa-doubtful	Grass
		Paspalum vaginatum (Seashore paspalaum)	North America	Grass
		Pennisetum clandestinum (Kikuyu grass)	Tropical Africa	Grass
		Phalaris arundinacea (Reed canary grass)	Europe	Grass
		Spartina alterniflora (Smooth cord grass)	South America	Grass
21.	Pontederiaceae	*Eicchornia crassipes* (Water hyacinth)	South America	Aquatic plant
22.	Rubiaceae	*Coffea arabica* (Arabic coffee)	Africa	Shrub
		C. canephora (Robust coffee)	Africa	Shrub
23.	Solanaceae	*Physalis peruviana* (Cape gooseberry)	South America	Shrub
		Solanum mauritianum (Wild tobacco tree)	South America	Tree
		Solanum sisymbriifolium (Tricky night shade)	South America	Herb
		Solanum viarum (Tropical soda apple)	South America	Shrub
24.	Salviniaceae	*Salvinia molesta* (Water fern)	South America	Aquatic plant
25.	Verbenaceae	*Lantana camara* (Wild sage)	Tropical America	Shrub

Table 12: List of Designated Biosphere Reserves (Source: MoEF, 2012)

S.No.	Name and total geographical area (km^2)	Date of designation	Location in the States /UT
1.	Nilgiri (5520)	01.08.1986	Part of Wynad, Nagarhole, Bandipur and Madumalai, Nilambur, Silent Valley and Siruvani hills (Tamil Nadu, Kerala and Karnataka)
2.	Nanda Devi (5860.69)	18.01.1988	Part of Chamoli, Pithoragarh and Almora Districts in Uttarakhand
3.	Nokrek (820)	01.09.1988	Part of East, West and South Garo Hill districts in Meghalaya
4.	Manas (2837)	14.03.1989	Part of Kokrajhar, Bongaigaon, Barpeta, Nalbari, Kamprup and Darang districts in Assam
5.	Sunderban (9630)	29.03.1989	Part of delta of Ganges and Brahamaputra river system in West Bengal
6.	Gulf of Mannar (10500)	18.02.1989	Part of Gulf of Mannar extending from Rameswaram island in the North to Kanyakumari in the South of Tamil Nadu
7.	Great Nicobar (885)	06.01.1989	Southern most island of Andaman and Nicobar Islands
8.	Similipal (4374)	21.06.1994	Part of Mayurbhanj district in Orissa
9.	Dibru-Saikhowa (765)	28.07.1997	Part of Dibrugarh and Tinsukia districts in Assam
10.	Dehang Debang (5111.5)	02.09.1998	Part of Upper Siang, West Siang and Dibang Valley districts in Arunachal Pradesh
11.	Pachmarhi (4981.72)	03.03.1999	Part of Betul, Hoshangabad and Chhindwara districts in Madhya Pradesh
12.	Khangchendzonga (2619.92)	07.02.2000	Part of North and West districts in Sikkim
13.	Agasthyamalai (3500.36)	12.11.2001	Part of Thirunelveli and Kanyakumari districts in Tamil Nadu and Thiruvanthapuram, Kollam and Pathanmthitta districts in Kerala
14.	Achanakmar-Amarkantak (3835.51)	30.03.2005	Part of Anuppur and Dindori districts of Madhya Pradesh and Bilaspur district of Chhattisgarh
15.	Kachchh (12,454)	29.01.2008	Part of Kachchh, Rajkot, Surendranagar and Patan districts in Gujarat
16.	Cold Desert (7770)	28.08.2009	Pin Valley National Park and surroundings; Chandratal and Sarchu; and Kibber Wildlife sanctuary in Himachal Pradesh
17.	Seshachalam (4755.997)	20.09.2010	Seshachalam hill ranges in Eastern Ghats encompassing part of Chittoor and Kadapa districts in Andhra Pradesh
18.	Panna (2998.98)	25.08.2011	Part of Pann and Chhattarpur districts in Madhya Pradesh

Table 13: Ramsar sites in India (26 Ramsar Sites, 689,131 hectares) (Source: http://www.ramsar.org/pdf/sitelist.pdf)

Site	Date of designation	Region, province, state	Area	Coordinates
Ashtamudi Wetland	19/08/02	Kerala	61,400 ha	08°57'N 076°35'E
Bhitarkanika Mangroves	19/08/02	Orissa	65,000 ha	20°39'N 086°54'E
Bhoj Wetland	19/08/02	Madhya Pradesh	3,201 ha	23°14'N 077°20'E
Chandertal Wetland	08/11/05	Himachal Pradesh	49 ha	32°29'N 077°36'E
Chilika Lake	01/10/81	Orissa	116,500 ha	19º42'N 085º21'E
Deepor Beel	19/08/02	Assam	4,000 ha	26°08'N 091°39'E
East Calcutta Wetlands	19/08/02	West Bengal	12,500 ha	22°27'N 088°27'E
Harike Lake	23/03/90	Punjab	4,100 ha	31º13'N 075º12'E
Hokera Wetland	08/11/05	Jammu and Kashmir	1,375 ha	34°05'N 074°42'E
Kanjli	22/01/02	Punjab	183 ha	31°25'N 075°22'E
Keoladeo National Park **MR**	01/10/81	Rajasthan	2,873 ha	27º13'N 077º32'E
Kolleru Lake	19/08/02	Andhra Pradesh	90,100 ha	16°37'N 081°12'E
Loktak Lake **MR**	23/03/90	Manipur	26,600 ha	24º26'N 093º49'E
Nalsarovar Bird Sanctuary	24/09/12	Gujarat	12,000 ha	22°46'33"N 072°02'21"E
Point Calimere Wildlife and Bird Sanctuary	19/08/02	Tamil Nadu	38,500 ha	10°19'N 079°38'E
Pong Dam Lake	19/08/02	Himachal Pradesh	15,662 ha	32°01'N 076°05'E
Renuka Wetland	08/11/05	Himachal Pradesh	20 ha	31°37'N 077°27'E
Ropar	22/01/02	Punjab	1,365 ha	31°01'N 076°30'E
Rudrasagar Lake	08/11/05	Tripura	240 ha	23°29'N 090°01'E
Sambhar Lake	23/03/90	Rajasthan	24,000 ha	27º00'N 075º00'E
Sasthamkotta Lake	19/08/02	Kerala	373 ha	09°02'N 076°37'E
Surinsar-Mansar Lakes	08/11/05	Jammu and Kashmir	350 ha	32°45'N 075°12'E
Tsomoriri	19/08/02	Jammu and Kashmir	12,000 ha	32°54'N 078°18'E
Upper Ganga River (Brijghat to Narora Stretch)	08/11/05	Uttar Pradesh	26,590 ha	28°33'N 078°12'E
Vembanad-Kol Wetland	19/08/02	Kerala	151,250 ha	09°50'N 076°45'E
Wular Lake	23/03/90	Jammu and Kashmir	18,900 ha	34º16'N 074º33'E

MR: Sites included in the **Montreux Record**, "a record of Ramsar Sites where changes in ecological character have occurred, are occurring or are likely to occur" maintained by the Secretariat in consultation with the Contracting Party concerned (Recommendation 4.8). www.ramsar.org/montreux-record

flagship programmes for the conservation of tiger and elephant. Among the protected areas, India has designated 18 as Biosphere Reserves (BRs) in different parts of the country (Table 12) (MoEF, 2012). Out of these, so far seven, viz., Nilgiri, Gulf of Mannar, Sunderban, Nanda Devi, Pachmarhi, Similipal and Nokrek have been included in the World Network of Biosphere Reserves of UNESCO, also termed as 'world heritage sites'. In July 2016, Kangchendzonga National Park (KNP) in Sikkim has also been named as a world heritage site by the World Heritage Committee (WHC) of UNESCO. For India this is the first UNESCO 'mixed' heritage site exhibiting qualities of both natural and cultural significance. Recognizing the importance and significance of wetlands, India has established 26 Ramsar sites covering a surface area of 689,131 hectares (Table 13). Apart from establishing protected areas and Ramsar sites, a National Biodiversity Act was passed in 2002 and biodiversity rules were framed in 2004. A National Biodiversity Action Plan has also been released.

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