DIGITIZATION OF DEHRA DUN HERBARIUM

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Negi, R., Chandra, A., Verma, P.K., Yadav, N., Verma, R., Beg, S., Johra, D., Kohli, G., Akhtar, Z. and Yadav, K.

Land plants (subkingdom – Embryophyta, hereafter 'plants') are a hyperdiverse clade of organisms, the principal providers of biochemical energy and habitat structure in most terrestrial ecosystems play a key role in maintaining ecological and evolutionary processes as well as human livelihoods (Meyer *et al.*, 2016). The world over, botanists and naturalists over past four centuries or so have collected, catalogued, and systematically stored plant specimens from terrestrial as well as aquatic ecosystems in herbaria. Thus, hundreds of herbarium collections have accumulated a valuable heritage and knowledge of plants over recent centuries. These biological specimens in research collections provide the most important baseline information for systematic research. Presently, according to the data in Index Herbariorum as of 31 December, 2021, the world has 3,522 active herbaria which curate 397.59 million specimens (Thiers, 2022). There are now 183 countries with at least one herbarium. Since 2011, 637 herbaria have been newly registered in Index Herbariorum, and the total number of specimens reported for all herbaria increased by 3.75 million (Thiers, 2022).

4.1

Herbaria – Scientific Heritage Enabling Novel Research

An herbarium is more than a mere collection of dried plant specimens. It is an exuberant output of botanical quest that scholars have accomplished over the period of time. Tournefort (1700), a French Botanist was first to use the term 'herbarium' to describe a collection of dried plants. Luca Ghini (1490-1556) an Italian physician and botanist was the first recorded owner of an herbarium. He was first to realize the advantage of processing and preserving specimens as a reference for botanical scholars. His earliest record is of 1551 when, Ghini sent some specimens to Mattioli. However, the oldest preserved herbarium specimen which is still existing in Florence, Italy, was collected by Gherardo Cibo, a student of Luca Ghini in 1532 (Heads, 2005). Herbarium record, like other historical repositories, are immense primary data source documenting phyto-diversity across space and time (de Lutio *et al.*, 2022). It provides a rapid view of floristic diversity of a region and presents a unique view of eco-evolutionary dynamics. Each specimen contains invaluable information such as phenotypic traits, geographic location, collection data and phenological details which can further be analyzed and correlated with studies on floristics, molecular systematics, phyto-geography, threat perception, impact of climate change, effect of anthropogenic activities, modeling past ecological processes or extrapolating future trends, etc. (Bakker *et al.*, 2020a). Herbaria are a major frontier for species discovery; 84% of new species description between 1970-2010 were based on preserved specimens housed in different herbaria across the world, with nearly one-quarter of new species descriptions involving >50 years' older specimens (Bebber *et al.*, 2010). Herbaria have also been the source for retrieval of ancient DNA to determine the genotype of plant pathogens. Yoshida *et al.* (2014) used herbarium specimen of potato to sequence the genotype of the *Phytophthora infestans* strain responsible for Irish potato famine in 1840s. DNA sourced from herbarium specimens collected between 1788 and 1975 was crucial in discovering herbicide resistance alleles in the grass weed *Alopecurus myosuroides*, prior to the commercial release of herbicides (Délye *et al.*, 2013). Using a sample set of nearly 8,000 herbarium specimens, Kates *et al.* (2021) have demonstrated that when DNA extraction and library building protocols are designed with herbarium specimens in mind, most herbarium specimens will provide suitable sequence for phylogenetic datasets. Old herbarium specimens have also been instrumental in shedding light on a C3 to C4 transition pathways (Besnard *et al.*, 2014). Studies in plant phenology have provided some of the best evidence for large-scale responses to recent climate change and flowering phenology (Jones and Daehler, 2018).

Herbarium specimens also tell stories beyond the plants themselves- about how a specimen may have languished for decades in obscurity until botanists with a keen eye recognized it as a new species or other allied professionals used them in phenological research or studying the impact of climate change (Soltis, 2017). The timing of phenological events such as leaf out and flowering, strongly influence plant success and their study is pivotal for understanding how plants will respond to climate change. Generally, phenological research, however, is often limited by the temporal, geographic, or phylogenetic scope of available data. Hundreds of millions of plant specimens in herbaria worldwide offer a potential solution to this problem as the herbarium specimens represent snapshots of phenological events and have been reliably used to characterize phenological responses to climate. Willis *et al.* (2017) have highlighted the potential of herbarium based phenological research using old plants and applying new tricks. Herbaria have a long tradition of communication and cooperation so as to assist plant scientists across the world and they are now extending support in terms of essential material and scientific basis for varied type of emerging researches in the fields of biodiversity conservation, ecology, genetic characterization, and climate change. Herbarium specimens collected over the past four centuries document the world's vegetation, including how it has changed in response to human activities and population expansion, and offer the enormous opportunity as basis for scientific names in the form of type specimens. Till recent past, the world's herbarium specimens were under lock and key and accessible to only a small number of scientific specialists. Moreover, the majority herbaria were facing multiple problems arising due to acute shortage of storage space, gradual decay of old plant specimens, and difficulty in handling of enormous collection of specimens by an herbarium itself. This situation led to the priority conservation requirement of modernization and digitization of world's herbaria.

4.2

Digitization of Herbaria – Old Plants and New Tricks for Potential Biodiversity Research

The distributed nature of the world's museum artefacts/ collections ensures long term security and preservation. However, invaluable herbarium collections are vulnerable to anthropogenic as well as natural calamities like theft, fire, cloud burst, flooding and water damage. The tens of thousands of plant specimens stored at the Berlin Herbarium were almost completely destroyed during the World War II (Phillips, 2010). Considering such kind of unforeseen circumstances, worldwide effort is being made to digitize and electronically channelize phyto-diversity data accumulated in estimated 397.5 million herbarium specimens, deposited in 3,522 herbaria (Thiers, 2022; de Lutio *et al.*, 2022). An estimated number of ca. 70,000 specimens comprise yet undescribed species housed in different herbaria (Bebber *et al.*, 2010; Bakker *et al.*, 2020b). Such collections are a valuable record of existing biodiversity across the globe and through time and space.

Digitization of herbaria is the process of supplementing natural history (plant) collections with digital data. It involves the curation, capturing and processing of a digital image of the specimen, transcribing the associated label and ledger text, and georeferencing locality information (Willis *et al.*, 2017). Digitization of herbaria has emerged as a global enterprise and increasingly specimen data and images are brought in the digital form from herbaria around the world (Soltis, 2017). In a short span of time, data aggregators dealing with the wider discipline of biodiversity *viz.*, the Global Biodiversity Information Facility (GBIF), Atlas of Living Australia (ALA), US Geological Survey's portal (Biodiversity Information Serving Our Nation- BISON), and iDigBio (Integrated Digitized Biocollections), funded by the US National Science Foundation (NSF) offer digital biodiversity data, including information from herbarium specimens (Soltis, 2017). In addition, a large number of national and regional indicators also serve biodiversity information, and collectively these aggregators provide data that allow visualization and analysis of patterns of biodiversity including herbarium specimens in novel and exciting ways. Digital repositories provide fast, easy and cheap access to millions of specimens for anyone with an Internet connection.

Although, decades have passed since the first herbarium records were databased and made available via the internet, it is only within the past few years that sufficient number of specimen records have been digitized and become available for large scale, innovative research. Herbarium digitization has greatly diversified use of herbarium data in scientific research and now being regarded as temporally and spatially extensive sources of data which is now extensively used in emerging fields of plant informatics, biodiversity genomics, evolutionary genetics, phylogenetic, domestication and population genomic studies, artificial intelligence for instance automatic taxon recognition from herbarium specimens, etc. (Staats *et al.*, 2013; Heberling *et al.*, 2019; Little *et al.*, 2020; Bakker *et al.*, 2020a). Certainly, digitization of herbaria specimens has opened new opportunities for synthetic analyses that connect digitized specimen data with other resources (phylogenetic, climatological, genomic, etc.) so as to address both novel questions in plant sciences and long-standing questions from new perspectives and larger scales (Soltis and Soltis, 2016; Soltis, 2017). The use of digitized herbarium records in varied type of plant and ecological researches have just begins to demonstrate the potential of these data. The world's herbaria are transforming, and collectively they offer newer avenues for synthetic research that can address pressing societal and global problems related to food security, conservation and climate change. Long ago, pioneers of herbaria as visionaries have visualized the enormous value of collections and promoted them. Today, digitization and technological breakthroughs in modernization of herbaria continue to enhance their value with time.

4.3

Dehra Dun Herbarium

The worldwide register of herbaria is maintained by the New York Botanical Gardens in the form of a useful global publication '*Index Herbariorum*', which provides concise information about a large number of herbaria across the globe (Holmgren *et al.*, 1990). In order to register in the *Index Herbariorum*, a unique acronym, as well as information about the size, collections, staff, contact person, and address are needed for each herbarium. Presently, this global Index includes details of 121 Herbaria in India which were created by Research Institutes/ Organizations, Universities and Colleges as well as by Private Organizations/ Foundations and are being maintained by them.

The Botany Branch, FRI, Dehra Dun has an herbarium of an ever-growing collection of authentic specimens. It is the best herbarium in the Eastern part of the world. The herbarium FRI, is known internationally as the 'Dehra Dun Herbarium (DD)'. It is the second biggest herbarium and the largest Forest Herbarium in the country. Herbarium of FRI have an old collection, representing different biogeographic zones of the country and beyond, particularly areas under the British India. DD Herbarium is composed of the collections of *Forest School Herbarium* started by J. S. Gamble in 1890, and the *Saharanpur Herbarium* started around 1816. In 1908 these two herbaria were merged and since the amalgamation to date, the total collection number has grown to ca. 3,30,000 specimens. There are 1,300 valuable 'Type specimens', which is actually the original specimen, selected to serve as a reference point when a plant species is first named. The oldest specimen housed in the herbarium dates back to 1807 and it was collected by Dr. Hamilton from Assam. Duthie and Gamble have put immense labour to bring together a good representation of the flora of North- Western region of the erstwhile Indian sub-continent.

4.3.1

Significant Contributions to DD Herbarium

The Saharanpur Herbarium was started some years after the establishment of the Botanical Gardens at Saharanpur in 1816. Dr. George Govan, Civil Surgeon, Saharanpur was its first Superintendent in addition to his own duties. The herbarium was established on the site of an old, 16 hectare dilapidated local garden which was founded by Zabita Khan, an eminent administrator and son of Nijab-ud- Doula with the revenue of seven villages for its maintenance (Table 4.1). He was succeeded by Dr. John Forbes Royle in 1823, and like his predecessor, combined the duties of Station Surgeon, Saharanpur with that of Superintendent of the Garden. He trained collectors and sent them into the hills for seeds and plants and wanted to know the plants alive. Dr. Hugh Falconer succeeded Royle in 1831. He had employed

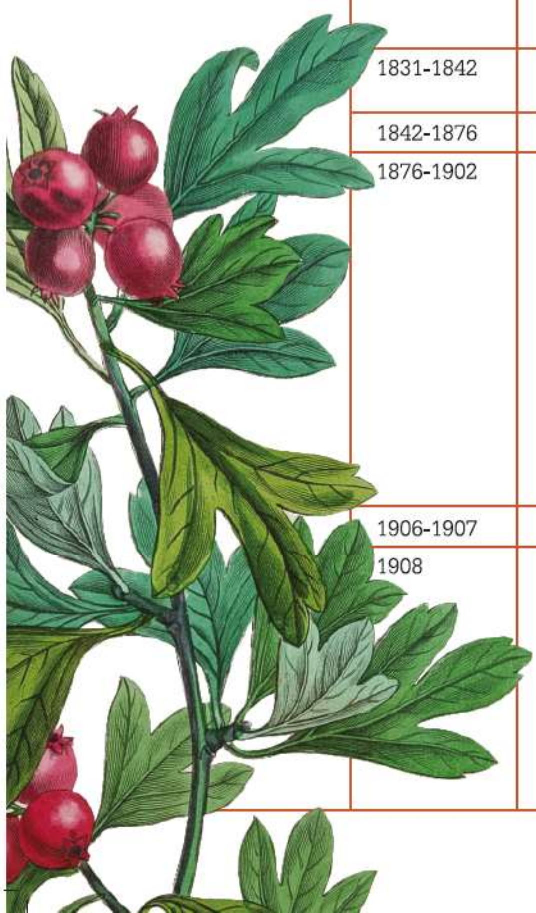
Indian plant collectors and his labels carry details about localities written in Persian or Devanagri script by his Indian collectors. Dr. William Jameson followed Falconer in 1842 and collected from Hawalbagh in Kumaon and the labels written by his collectors are mostly in Persian script. His contribution in the field of economic botany is the establishing of the tea industry, potato and flax in Northern India (Dehra Dun and Kangra). During his 33 years of service in Saharanpur, there were several periods of leave. In one of them acted J. L. Stewart (author of *Punjab Plants*) and in 1868 George King (subsequently Superintendent, Royal Botanic Gardens, and Calcutta) officiated for him. After Jameson's retirement in 1876 the post of Superintendent went outside the Medical Service. J. F. Duthie, Professor in the Agricultural College at Cirencester was appointed as Superintendent and in 1887 he became the first Director of the Botanical Department of Northern India. He was a man of strong taxonomical interest and immediately after taking up the new assignment set to work, putting the older collections in order. Prior to Duthie's time plant collections were displayed in a museum which was filled with miscellaneous collections including animals, mostly birds, as well as many kinds of vegetable products such as fibers, drugs, rock specimens, fossils, etc.

During Duthie's time, Gamble, an ardent botanist and collector, was vigorously building up the *Forest School Herbarium* at Dehra Dun. Several private herbaria made by forest officers appear to have been presented, viz., by Smythies, Gustav Mann (Assam collection) and J. C. McDonnell from Kashmir and others. By exchange, a number of foreign collections were received from various parts of the world. Among the collections added to the Herbarium may be mentioned those of Lace, Haines, Parker, Parkinson, Bor, Stewart, Mooney, Raizada and many sent by forest officers and others from all parts of India and Burma. In 1908 Saharanpur Herbarium (established in 1816) and Forest School Herbarium (established in 1890) were amalgamated into DD Herbarium. The herbarium's total holdings number around 3,30,000 specimens, and include angiosperms, bryophytes and pteridophytes. After inception of the Indian Council of Forestry Research and Education (ICFRE), areas under jurisdiction of FRI are Uttarakhand, Uttar Pradesh, Delhi, Punjab and Haryana. During recent time, researches on qualitative and quantitative aspects of biodiversity are also being carried out.

Table 4.1 Notable Contributions to DD Herbarium

Significant Contributions to DD Herbarium

Under the Aegis of	Period	Significant Contributions (Wholly or partly terra incognita)	
British Colonial Rule	1816-1823	Dr. George Govan	Erstwhile Sirmoor State.
	1823-1831	Dr John Forbes Royle	Army officer Lieutenant Maxwell collected about 100 species for him from Kunawar and adjacent areas. He sent collectors to Kashmir under guidance of shawl dealers.
	1831-1842	Dr. Hugh Falconer	Trans-Indus territory, Kashmir and Ladakh, Gilgit
	1842-1876	Dr William Jameson	Hawalbagh in Kumaon.
	1876-1902	J. F. Duthie	Himalayan regions of Yamunotri, Gangotri, Kumaon, West Nepal, Tibet frontier, Garhwal, Almora, Jaunsar-Bawar; Kheri, Gonda, Bahraich, Bijnor and Pilibhit in the then Uttar Pradesh; Ajmer, Merwara, Mt. Abu in Rajasthan; Chanda, Nimar, Nagpur and Jabalpur in Maharashtra and Madhya Pradesh, respectively; Ambala, Hissar and Multan, West Nepal and erstwhile Kashmir State.
	1906-1907	H. H. Hains	Bihar and Orissa
	1908	Establishment of Dehra Dun Herbarium	Amalgmation of Saharanpur Herbarium and Forest School " Herbarium Private herbaria of forest officers *viz.* Smythies, Gustav Mann, J.C. McDonnell etc. Foreign collections on exchange bases as Australian plants from Baron Von Mueller



Conservation of Forest Genetic Resources

National Program for Conservation and Development of Forest Genetic Resources

Pilot Project

Under the Aegis of	Period	Significant Contributions (Wholly or partly terra incognita)	
	1907-1922	R. S. Hole	United Province
	1922-1932	R.N. Parker	Kali Valley (Kumaon), Delhi, Tavoy, Mergui and Tenasserium (Burma), Bashahr and Kullu, Etawah and Northern Bengal, Kashmir, Nepal, Burma and Andaman Islands
	1932-1937	C.E. Parkinson	Burma and Andaman Islands
	1937-1942	N.L. Bor	Lahaul, Sikkim, Manipur, Nagaland, Meghalaya, NEFA, Tibet
Government of India Post-independence)	1942-1963	M. B. Raizada	Gir forests of Saurashtra, United Province
	1963-1969	K. C. Sahni	Andaman and Nicobar Islands, Sikkim, Panvha-chuli, Kedarkanta, Goa, Daman and Diu, Arunachal Pradesh
	1969-1981	K.M. Vaid	Ladakh
	1981-1984	K.N. Bahadur	Arunachal Pradesh, Goa, Daman and Diu
	1979-1984	S. S. Jain	Kameng and Subansiri districts of Arunachal Pradesh
	1969-2003	H. B. Naithani	Sikkim, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Manipur, Goa, Andaman and Nicobar Islands, Haryana, Delhi, Bihar, Andhra Pradesh
	1992 onwards	Establishment of ICFRE	Area under jurisdiction *viz.*, Uttarakhand, Uttar Pradesh, Delhi, Punjab and Haryana

4.3.2

Need for Modernization of DD Herbarium

DD Herbarium was established more than 100 years ago and during this period enormous advancement in herbarium management in terms of infrastructure and methodology took place all over the globe. DD Herbarium has ca. 3,30,000 specimen collection and there are other valuable specimens of earlier researchers from late 1980s to 1990s which are yet to be incorporated. These specimens couldn't be incorporated due to the space constraint. A need for the expansion and modernization of DD Herbarium was realized. Moreover, being the second largest herbarium of the country, the collections offer a unique glance into the flora of the Indian subcontinent. In order to make the herbarium data available to taxonomists worldwide, the need for developing a digital database was also felt. Hence, efforts to digitize the herbarium specimens first began in early 2007 through a joint effort between the FRI's Forest Informatics Division and the Systematic Botany Discipline, availing a grant from ICFRE. As a result, digitization of ~34,000 specimens were accomplished. Subsequently, as a part of the present CAMPA supported CoE-FGR project, planned renovation, modernization, and digitization of DD Herbarium was initiated in 2016.

4.3.3

Objectives

The important task on renovation, modernization and digitization of DD Herbarium included the following objectives:

(a) Renovate the existing herbarium so as to enhance the storage space for specimens, incorporate newer facilities and modern gadgets.

(b) Provide the long-term preservation to the valuable specimens by reducing the need for physical handling and carry out digitization of existing specimens.

(c) Develop a digital database of DD Herbarium specimens to facilitate global access to the collection.

4.3.4

Material and Methods

The task on renovation and digitization of herbarium involved several key steps described below:

4.3.4.1

Renovation, Installation of Mobile Compactors and Relocation of Herbarium Specimens

This subcomponent of the task on renovation and modernization of DD Herbarium was of paramount importance aiming for enhancement in space, development of facilities, technology upgradation, and transfer of herbarium specimens to the new hall.

(a) Renovation

In order to safeguard and expand the valuable plant specimens incorporating FGR for improved access and facilitate wider use by the scientific community, the hall on the ground floor in the herbarium building required renovation so as to raise its holding capacity for incorporation of more specimens. The old system of the herbarium included assorted vintage wooden and steel almirahs (type specimens) with almost no scope of further addition of specimens. Hence, expert consultations were availed from varied professionals. Proposed renovation of the hall envisaged the enhanced opportunity to expand the arena with a new area for storage with compact storage facility through incorporation of mobile compactors (movable steel almirahs). The refurbished hall was expected to hold the valuable collection of Dicotyledonous flora. New Digitization lab with computers with separate facility for herbarium scanner was also provisioned. Besides adequate and proper storage space, air conditioning of the entire facility was planned in order to curb the likelihood of insect-pest infestation problem.

(b) Technology Up-gradation

In addition to enhancement in space and facilities, the other important requirement foreseen was relevant to technology upgradation of existing equipment and addition of modern gadgets so as to facilitate high resolution imaging of specimens and establishment of database. In view of this, one Epson Expression 12000XL A3 Flatbed Photo Scanner, three new high end desktop computers, etc. were planned to be procured.

(c) Transfer of Herbarium specimens to new Herbarium Hall

With completion of renovation of herbarium hall, voluminous task of transferring Dicotyledonous floral specimens was initiated since February, 2017 following the Bentham and Hooker classification.

4.3.4.2

Review of Literature

The term 'virtual herbarium' or 'digital herbarium' has widely been applied for a web-based collection of digital images of preserved plants or their parts. Over the past decade or so, considerable progress has been achieved in the creation of digital assets from herbarium specimens, and in the dissemination of this information. One of the major advantages of digitization is that the specimen morphology can be visualized without damage to the original specimen. The high-resolution images of digitized specimens can be magnified; hence researchers can examine micro-morphological features of plant parts and can further access specimen information that has already been recorded on the data sheet. International herbaria like the Herbarium at the Royal Botanic Gardens Kew; C. V. Starr Virtual Herbarium at New York Botanical Garden; Geneva Herbaria Catalogue; RBGE Herbarium Catalogue of Edinburgh, etc. have opened up their digital collections to a wider audience (Thiers *et al.*, 2016; Clerc *et al.*, 2017; King *et al.*, 2019). Likewise, the major initiatives on digitization of herbaria in India have been accomplished by the Indian Institute of Science Herbarium; Herbarium, Raw Drug Repository of FRLHT; Herbarium of JNTBGRI; Janaki Ammal Herbarium in the Indian Institute of Integrative Medicine; Herbarium of French Institute of Pondicherry; and Herbarium of Regional Plant Resource Center, Odisha (Rao *et al.*, 2012; Singh *et al.*, 2019).

Fig 4.1 Renovation of Herbarium, Installation of Mobile Compactors and Relocation of Herbarium Specimens Following Bentham and Hooker's System of Classification

In order to update the information on species under the 'species database', a review of existing national and regional floras and other documents was envisaged. The species database included variables like family name, genus name, species, sub-species, variety, synonym, common name, English name/ trade name, vernacular name, altitude, flower colour, habit, habitat, and details on distribution. Thus, primarily, floras *viz.*, the Flora of British India (Hooker, 1875-1897) and Flora of India (Hajra *et al.*, 1995a and b, 1996, 1997; Sharma *et al.*, 1993a, b and c; Singh *et al.* 2000a and b) were consulted being the consolidated account of the floral diversity of the country. In addition, a large number of regional floras and other publications were also reviewed for species details. These included floras/ publications *viz.*, Kanjilal (1901); Hole (1911, 1913, 1917, 1918a and b); Haines (1912, 1914, 1921-1925); Parker (1914, 1924, 1938); Parkinson (1930); Raizada (1934, 1941a and b, 1951, 1954a and b, 1976); Raizada *et al.* (1957 and 1983); Bor and Raizada (1954); Sahni (1953, 1958 and 1969); Sahni and Raizada (1955); Sahni and Dayal (1970); Sahni *et al.* (1972); Deva and Naithani (1974); Naithani and Raizada (1977); Naithani and Tiwari (1982-1983), Naithani *et al.* (1985 and 1997), Biswas (1985 and 1988), Biswas and Ahmed (1987); Jain and Chandra (1986); Negi and Naithani (1995); and Balakrishnan *et al.*, 2012. Further, besides the printed literature, other information available online on worldwide web have also been optimally utilized for supplementing the information for species database.

4.3.4.3

Digitization of Herbarium

Herbarium collections represent an important source of information for species identification among other activities related to botanical studies. The collections are constituted from plant specimen taken in the field and mounted on herbarium sheets according to a precise set of procedures for future reference. Nowadays, referencing of herbarium specimen can be made through the internet provided the sheets have been digitized and put online. This has many advantages and largely depends on the digitization process of the herbarium specimen in order to have high quality images. This can be achieved by a scanner or by digital photography. As stated earlier, digitization of herbarium specimens broadly involves the curation, capturing and processing of a digital image besides transcribing the associated label and ledger text and georeferencing locality information. The deliberations on the need to digitize DD Herbarium and create database was initiated in late 1990s and a plan project entitled 'Computerization of Herbarium of Forest Research Institute, Dehra Dun' was executed during 1997-2002. In all, 600 type specimens and species diversity of 30 genera and 80 species and 75 rare and threatened forest species particularly belonging to Uttarakhand were studied for their nomenclature and taxonomic details and to incorporate in a database. Later, with the technical assistance of Forest Informatics Division of FRI, the digitization of DD Herbarium was initiated in 2007 and an offline herbarium database named 'Digital Herbarium Specimen Database' was developed to serve as a computerized catalogue. During this phase, altogether 33,987 species were covered. The actual digitization of DD Herbarium for an online dissemination was commenced as a part of the CAMPA supported project. The process of digitization adopted in the present task included steps, depicted in Fig. 4.2.

(i) Specimen Screening and Data Preparation:

An authentic and undamaged herbarium specimen was selected and tagged for the digital photography. Emphasis was laid on the selection of specimens with availability of intact floral parts/ fruit details as prime requisition for species identification because taxonomic identification keys are based on floral descriptions. Species details were prepared by consulting relevant floras (regional, national as well as international) as described in above section 4.3.4.2. Online literature was also accessed from time to time for correct nomenclature and other details, and they were suitably incorporated.

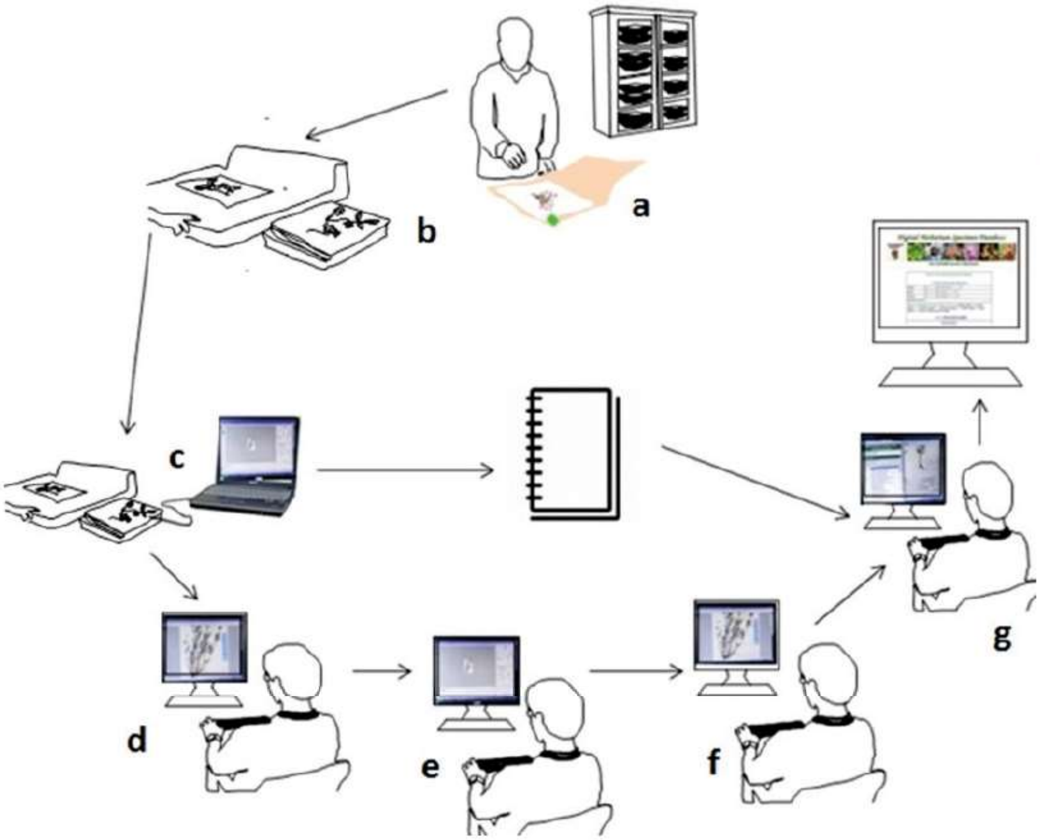


Fig4.2 : Herbarium Digitization Methodology (a) Tagging of the Specimens; (b) Scanning of Tagged Specimen; (c) Data Transfer; (d) Image Processing; (e) Preparation of Species Details; (f) Uploading Image; and (g) Data Entry and Herbarium Database

(ii) Herbarium Specimen Scanning:
The Expression 12000XL was used for excellent A3 scanning performance. With its 2,400 high optical dpi resolution, 3.8 Dmax, 48-bit colour depth and optional transparency unit, imaging for consistently impressive results was performed while using photo restoration software. LED light source having scanning transparencies and auto focus function helped to achieve clearer and sharper images. A standard ruler or scale bar with FRI logo was added to the image so that the users who download a specimen image use the ruler to calibrate their own software for taking measurements, or use the ruler as a scale so that they can enlarge the specimen image to its actual size.

(iii) Image Processing and Data Entry:
Photoshop tool or other image processing applications were used to clear undesired elements. As a part of the data entry, four kinds of information were entered so as to generate databases on family, genus, species and specimen. The Family Database included name of the family while in the Genus Database, name of the genus was entered using the drop-down option. The Species Database provisioned for inclusion of varied available information collected from different literature sources. The Specimen Database incorporated all the information available as labelled data on the herbarium sheet furnished by collector/ depositor, determinavit (annotation remark), etc. Any other information, if available which doesn't fit in to the above category than the same was furnished under remarks column.

(iv) Image Uploading:
After entering all the details on above stated four types of databases, at last the scanned images were uploaded into the digital herbarium database (Fig. 4.2).

(v) Database Creation:
A Client Server Based Architecture Herbarium Database software was developed by the IT Cell, Forest Informatics Division of FRI in MySQL. The database thus generated by way of image processing of herbarium specimens and entry of relevant data was made available on the worldwide web (https://ddherbarium.icfre.gov.in/) for dissemination of important herbarium-based information and its wider use in newer researches.

4.3.5

Research Findings and Achievements

The renovation, modernization and digitization of DD Herbarium, an inheritance of over 200 years of botanical activity has not only given a new lease of life to old plant specimens but also significantly contributed by way of: (a) resolving space crisis; (b) safeguarding precious herbarium specimens and carpological artefacts and their preservation; (c) creating organized digital database based on scanned images and inclusion of valuable information on species; (d) facilitating dissemination of information and wider use through web portal; (e) getting insight on spatio-temporal area specific information; and (f) identifying gaps in collection specific to the time period, region, family, genus, and species. Important findings and achievements are described below:

4.3.5.1

Databasing of DD Herbarium Specimens

A notable achievement of DD Herbarium in two phases: (a) ICFRE supported, and (b) CAMPA fund supported has allowed digitization and databasing of 1,01,987 specimens or nearly one-third of the estimated total size of the collection. During the present phase under CAMPA fund, 68,000 herbarium specimens were digitized and databased while the remaining 33,987 specimens were digitized and databased in the earlier phase. A fully databased material with high quality images is available for all the specimens, which are accompanied by complete collection label information, along with the plant name and the family in which it is placed. The present database includes the following:

Family Database

Altogether, 200 families of phanerogamic flora as mentioned in Bentham and Hooker system of classification have been entered in to the database. Top ten dominant plant families are shown diagrammatically in Fig. 4.3. These families based on the descending number of specimens included in the database were: Leguminosae, Gramineae (Poaceae), Compositae (Asteraceae), Cyperaceae, Rosaceae, Labiatae, Rubiaceae, Orchidaceae, Euphorbiaceae, and Scrophularineae.

Genus Database

So far, species belonging to 5,091 genera has been entered into the digital herbarium specimen database (Fig. 4.4). Genera are arranged in DD Herbarium following *Genera Plantarum* by Bentham and Hooker.

Species Database

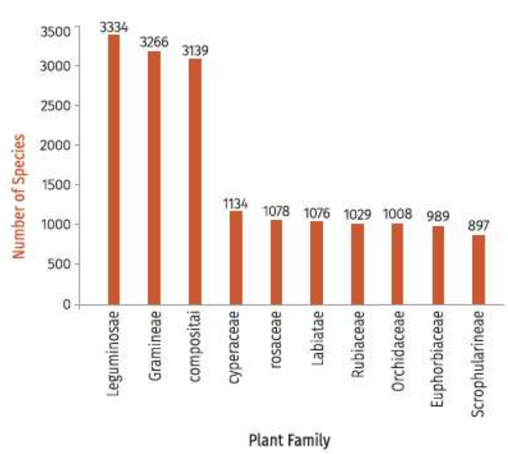
Specimens belonging to 33,987 species have been entered into the digital herbarium specimen database belonging to phanerogamic flora (angiospermic as well as gymnospermic flora) housed in DD Herbarium. Arrangement of species housed in DD Herbarium is based on Flora of British India by Hooker whereas plants discovered and/or described post Flora of British India are placed after the former species for convenience. Efforts have been made to incorporate all the available data from literature sources specified in the review of literature.

Specimen Database

A total of 1,01,987 specimens have been entered so far into the digital herbarium specimen database. Under the specimen database, all the information available on labelled data of herbarium sheet was incorporated.

The DD Herbarium is not only a globally important source of specimens for taxonomic and morpho-anatomical studies, but it has also become a major and highly promising source of data for FGR species that can address an array of new investigations dealing with plant systematics, biodiversity conservation, the impact of climate change, plant evolution and many other subjects.

Fig 4.3 - Top Ten Dominant Plant Families of Dehra Dun Herbarium



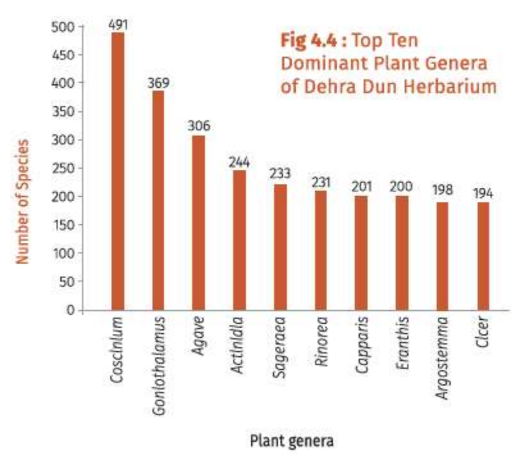


Fig 4.4 : Top Ten Dominant Plant Genera of Dehra Dun Herbarium

4.3.5.2

Spatial Coverage of DD Herbarium Database

Since inception, collections at DD Herbarium are global in scope as plant specimens have been received from far flung places across the globe. In its formative phase, particularly during the time of British India, collections received were broadly categorized and distributed into ten geographical zones so as to facilitate curation, easy access, and conduct of regional studies/ analyses. Accordingly, ten broad geographical zones defined during the British India time included: (i) North-West and Central India (Kashmir, Afghanistan, Baluchistan, Sindh, Punjab, Rajputana, Ajmer, Central India, Central Provinces, United Provinces, Nepal, Behar, Chota Nagpur); (ii) Bengal Assam and Burma (Bengal, Bhutan, Sikkim, Assam, Burma, Shan States and Andaman and Nicobars); (iii) South India (Bombay, Hyderabad, Mysore, Coorg, Madras, Ceylon and Laccadives); (iv) Asia, East of India (Siam, Indo-China, Malaya, the Dutch East Indies, Philippines and Micronesia); (v) Asia, North of India (Tibet, China, Japan, and Asiatic Russia); (vi) Asia, West of India (Turkestan, Persia, Arabia, and Asia Minor); (vii) Europe; (viii) America; (ix) Africa and (x) Australasia (Australia, Tasmania, New Zealand, Polynesia and New Guinea). DD Herbarium still maintains this broad-based distribution scheme of plant specimens (Fig. 4.5).

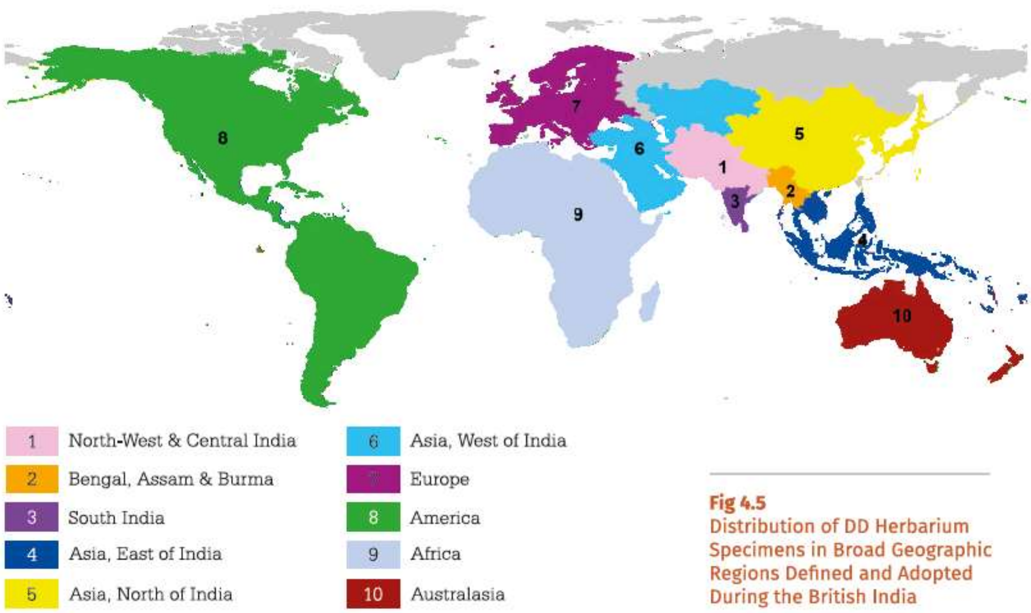


Fig 4.5
Distribution of DD Herbarium Specimens in Broad Geographic Regions Defined and Adopted During the British India

4.3.5.3

Databasing of Nomenclatural Type Specimens

Initially, databasing and producing high-resolution images of all the 'Type Specimens' held in DD Herbarium was executed. A total number of 1,289 nomenclatural type specimens were digitized and only types already placed in special Type almirahs were considered. However, given that no systematic searches were made to detect previously unrecognized types and specimens received under botanical exchange programs, it is expected that a significant but unknown number of types remains to be found among the general herbarium collections.

4.4

Key Messages and Priority Actions

The DD Herbarium, primarily a forest-based collection of ca. 3,30,000 plant specimens is one of the oldest and well-known herbaria and is a repository of valuable wealth of phanerogams (angiosperms and gymnosperms) and vascular cryptogams mounted on herbarium sheets. The DD Herbarium also includes a carpological (dry fruits and seeds) collection of ca. 1,000 specimens. Additionally, it holds an estimated 1,300 Type Specimens and historically important collections from various expeditions sent out from this herbarium to then partly or wholly *Terra Incognita* (unexplored or underexplored parts) of British India *viz.*, Indo-Nepal and Indo-Tibet border, Andaman and Nicobar Islands, Gir Forests, erstwhile Tehri Garhwal State, Sikkim, Goa, Daman and Diu, and Ladakh. Details about localities written in Persian or Devanagri script from the expeditions to Gilgit, Kashmir and Ladakh under the guidance of Falconer and to Hawalbagh in Kumaon by Jameson with Indian collectors are of inquisitive and historical significance.

4.4.1

Achievements

The Pilot Project on conservation of FGR has immensely helped the DD Herbarium in the process of its renovation by way of transforming the old building and its infrastructure as a modern facility with provisioning of multiple units of compactors replacing old wooden/ steel almirahs besides new air conditioners and equipment for digitization (scanner and image processers, computers, etc.). This activity has contributed towards the creation of additional storage space and offering new lease of life to old plant specimens/ herbarium sheets. The digitization process of DD Herbarium began initially with the support of ICFRE grant in 2008 and further financed under the current CAMPA sponsored Pilot Project has facilitated the successful completion of the digitization process of nearly one-third overall specimens. The digitization process has not only allowed easy access of the huge collection, but also wider global dissemination and enhanced visibility through worldwide web besides creating an archive of DD Herbarium.

4.4.2

Limitations

- Digitization of nearly one-third specimens has been completed. Thus, about two-third task of digitization of remaining specimens is still pending and it requires resolute and continued support for the completion of whole vital exercise.
- The DD Herbarium currently follows the Bentham and Hooker classification for distribution of specimens. In long run for the optimum use, it would require to either convert or have compatibility to link with the APG III system of flowering plant classification which is the third version of a modern, mostly molecular-based system of plant taxonomy being developed by the Angiosperm Phylogeny Group (APG).
- DD Herbarium initiated and developed during the regime of British India, thus, distributing/ arranging plant specimens in ten highly broad regional localities misleading the exact identity on the basis of specific country/ provinces. Presently, the current database face difficulties in responding to queries related to distribution of plants on the basis of India's States/ UTs and Districts. Database currently allows viewing scanned images and other details of plant specimens by selecting through family/ genus/ species. Query and report generation based on the locality, time period, etc., are inadequate.
- In several instances, digitization of some specimens was difficult on the account of illegible hand-writing and incomplete information about the full date of collection as several herbarium sheets have year data in last two digits format only, causing uncertainty whether the plant specimen was collected in 19th or 20th century.
- Updating nomenclature of plant species was challenging in view of multiple synonyms. The fraternity of forest botanists/ taxonomists is declining drastically. Hence, there is an urgency to undertake the digitization of remaining specimens on the highest priority and also to make efforts to create a pool of budding taxonomists.
- In recent decades, the branch of Systematic Botany and associated DD herbarium have been overlooked and received meagre annual grants causing acute fund constraints for undertaking field surveys and exploratory works. The annual contribution of new collection is thus declining.

4.4.3

Recommendations and Priority Actions

There is urgency to complete the process of digitization and creation of database by attending remaining nearly two-third specimens of DD Herbarium. Specimens also need updating of their nomenclature in view of the advances in taxonomy, merging of synonyms, and moving a plant from one family/ genus/ species to the newer category. The reclassification of the arrangement of herbarium by localities seems to be difficult considering the vast and old collection. However, augmentation of database fields by adding/ defining description of newer names of States/ UTs/ Districts or even Countries would be desirable. The present software of database needs to be updated in order to provide enhanced opportunity for query and report generation.

Certainly, the DD Herbarium is not only a globally important source of information to specialists of different plant groups/ families/ genera in revisionary/ monographic work all over the world in having a better understanding of the groups they study, but it has also become a major and highly promising source of data that can be helpful in novel research relevant to different emerging disciplines *viz.*, phenological, molecular, pathological, and climate change research, and biodiversity conservation.

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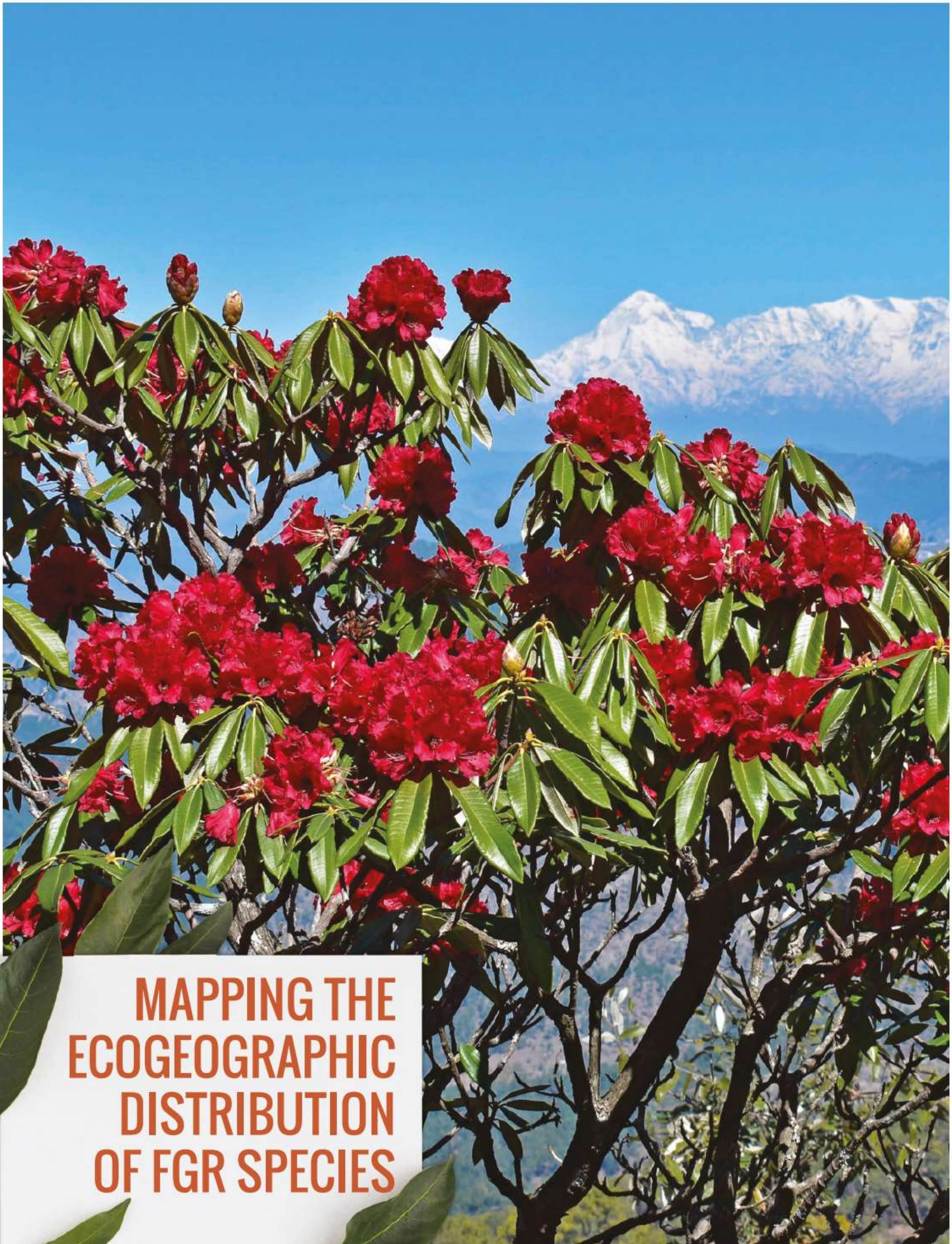
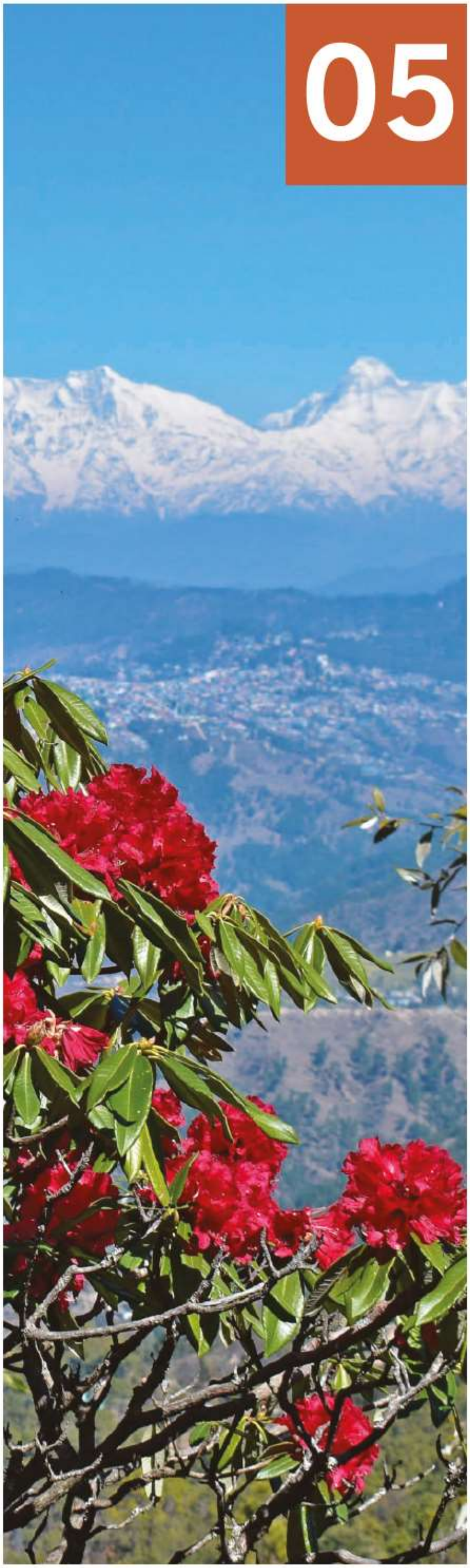
MAPPING THE ECOGEOGRAPHIC DISTRIBUTION OF FGR SPECIES





05

Bhandari, M.S., Shankhwar, R. and Pant, D.

In biology, the geographical area within which a species can be found has been referred as the 'range of a species'. Often, a distinction is made between a species natural, indigenous or native range, where it has historically originated and lived, and the range where a species has more recently established itself. Several terms are being used to describe the new range, such as non-native, naturalized, introduced, transplanted, invasive, or colonized range (Colautti and Hugh, 2004). The appearance of a plant species or a plant group in a given area is not accidental, but occurs in response to changes in climatic, topographic, edaphic and biotic factors (Gholinejad *et al.*, 2012). Within the range, 'species distribution' is the manner in which a biological taxon or the populations of a species are spatially arranged. The growing literature on conservation of biodiversity reveals that a large number of wild plant and animal species are showing signs of reduced or shrinking range owing to wide array of natural and anthropogenic factors, particularly, increasing human disturbances. Disjunct distribution occurs when two or more areas of the range are considerably separated from each other geographically. Besides disjunct distribution, a species may have uniform, random or clumped distribution. In uniform distribution, species are evenly distributed which means that all individuals are separated by a roughly consistent distance. This is usually a common type of distribution due to either resource competition or the territorial nature of the individuals. The random distribution is the rarest and it appears when a species has less need for social contacts between individuals or when resource competition is low. The clumped distribution is more or less a regular occurrence, and in this type of distribution, individuals clump together and form a small patch so as to help each other gather resources in areas with sparse resources, and also due to the requirement for protection. One of the most pervasive factors limiting the distribution of a species is anthropogenic disturbance, which may impact the range of species through habitat loss, alteration, or degradation, pollution, disease, introduction of non-native species, over-harvesting, and global climate change. A combination of historical factors *viz.*, speciation, extinction, continental drift, and glaciation usually explain the patterns of species distribution across its range.

Recognizing the importance of understanding species range and distribution, the development of 'biogeography' as a science dealing with the study of distribution of species and ecosystems through geological times began in the mid-18th century as Europeans explored the world and described the biodiversity of life (Mani, 1974). As biological communities and organisms vary in their distribution along geographic gradients of latitude, elevation, isolation and habitat area, biogeography that unites concepts and information from ecology, evolutionary biology, taxonomy, geology, physical geography, palaeontology, and climatology started providing much desired vital information on the distribution of ecosystems and associated floral and faunal species in a specified geographic space, an essential foundation for conservation planning at the national, regional and global levels. Branches of biogeography *viz.*, phytogeography and zoogeography cover studies about the distribution of plants and animals, respectively. The global community, particularly conservationists in 1960s started realizing that wild plant and animal species, the building blocks of biodiversity are on decline at an unprecedented rate mainly due to enhanced anthropogenic activities. Thus, concerns for conservation of biodiversity with greater focus on natural ecosystems and associated species diversity by way of adoption, ratification and implementation of the UNCBD by the member countries came in forefront. As a result, besides the development of biogeography as a discipline, concurrently in past three decades or so, voluminous literature also grew on species biology and ecology, more specifically on two interrelated disciplines *viz.*, wildlife habitat relationship (WHR), and species environment relationship (SER) (Morrison *et al.*, 2006; Thrush *et al.*, 2005; Allen and Starr, 1982; Cushman and McGarigal, 2004). More recently, the literature on 'ecogeographic' or 'eco-distribution' mapping of varied species based on the predictive 'Species Distribution Models (SDMs)' has also grown exponentially in a short span of time (Guarino *et al.*, 1995 and 2005; Franklin, 2009; Van Zonneveld *et al.*, 2011). Mapping of actual or potential species distributions or habitat suitability are often required for varied aspects of environmental research, natural resource management and conservation planning. These applications include biodiversity assessment, biological reserve design, habitat management and restoration, species and habitat conservation plans, population viability analyses, environmental risk management, invasive species management, community and ecosystem modelling, and predicting the effects of global environmental change on species and ecosystems (Franklin, 2009).

5.1

Ecogeographic Distribution

Maxted *et al.*, (1995) defined ecogeographic studies as the process of collecting, characterizing, systemizing and analyzing different kinds of data pertaining to target taxa within a defined region. Ecogeographic studies can contribute pivotal information on plant/ forest genetic resources so as to assess their conservation status and prioritize areas for conservation. They have also proven useful for effective gene bank management. Ecogeographic studies are being targeted on species of concern for the formulation and implementation of effective conservation strategies (Guarino *et al.*, 2005). For most plant species, including several crop wild relatives, and socio-economically as well as ecologically important FGR species, only limited amount of information on their natural distribution is currently available (Nic Lughadha *et al.*, 2005). In recent years, a large number of statistical and related methods have been used with mapped biological and environment data in order to model, or, in some way, spatially interpolate species distributions, and other bio-spatial variables of interest, over large spatial extents. This practice widely known as 'distribution modelling', 'ecological niche modelling' or 'species distribution modelling' is important and considered a useful tool to estimate the probable distribution for overcoming the lack of concrete information on natural distribution of species (Guarino *et al.*, 2002; Hernandez *et al.*, 2006; Franklin, 2009; Bhandari *et al.*, 2021). Such modelling aims to distinguish between zones where the species could potentially occur (i.e., areas with similar environmental conditions to the defined ecological niche) and areas where the species is likely to be absent because the local environment is different from the ecological niche. Based on the records of presence and absence of a species in a given area, distribution models are being developed so as to predict the full natural distribution range of plant species by defining the ecological niche of a species relying on statistical (empirical) relations between occurrence and environmental factors. Since, the collection of absence records is a problematic task owing to the fact that often the reasons for absence are not always clear; it could be either due to ecological characteristics, human disturbance or simply because species presence was overlooked during field surveys, inventory or collection, hence, generally, presence records only are being preferred for distribution modelling. Presence records can also be derived from herbarium specimens, gene bank accessions or vegetation/ plant species inventories, which have become increasingly available online through varied portals (e.g., Global Biodiversity Information Facility-GBIF; JSTOR Plant Sciences; Botanical Research and Herbarium Management System-BRAHMS) (Van Zonneveld *et al.*, 2011). Ecogeographic distribution or ecodistribution mapping is also used to understand the full distribution range of a species, and to identify gaps for prioritization of areas for collection of germplasm. A gap refers to a location where a distribution model predicts the potential occurrence of a target taxon, but where specimens and/ or germplasm of the taxon have not actually been collected (Jarvis *et al.*, 2005; Scheldeman *et al.*, 2007; Van Zonneveld *et al.*, 2011). Ecogeographic modelling is being increasingly used to examine the impact of climate change on the distribution of plant species of interest, particularly of socio-economic importance or FGR species (Jarvis *et al.*, 2008; Sáenz-Romero *et al.*, 2006). Information about species distribution through ecogeographic mapping can be used as an indicator to assess the conservation status of the natural populations of particular plant taxon. A species with a narrow and/ or fragmented natural distribution are more vulnerable to threats such as changes in land use and climate than a species with an extensive and continuous distribution (Van Zonneveld *et al.*, 2011). Mapping and modeling species distributions is becoming increasingly important for a variety of control and decision applications. Conservation of biodiversity, species protection, species reintroduction and prediction of potential impact of land use or climate change, are all areas of forest management. It requires detailed information based on the knowledge of species distribution and the relationship with environmental variables. SDMs are the most common method for determining a species' actual or projected global distribution and are used to identify the environmental conditions that determine suitable (probability range) environment for a species (Pearson, 2007).

5.2 Species Distribution Models

The SDM is a set of procedures, definitions, and techniques based on biogeographical and ecological concepts about the relationship between species distribution (or other biotic response variables describing aspects of biodiversity) and the physical (abiotic) environment (Holdridge, 1947; Whittaker *et al.*, 1973). SDMs are the empirical models that relate species occurrence to environmental variables using statistical or other response surfaces. SDMs use raster-based layers as predictors of suitable habitats, such as land use/ land cover, elevation, precipitation, temperature, and vegetation indices. This data is then combined with species presence data collected on the ground in statistical models and theoretically developed response curves to determine correlations between observed occurrences and the environmental factors, and generate habitat suitability map for a given species (Guisan and Thuiller, 2005; Elith and Leathwick, 2009; Liu *et al.*, 2009). In short, SDMs are quantitative empirical models of species–environment connections often built to utilize data on species distributions (abundance and occurrence) and environmental variables that are thought to influence species distributions.

SDMs are categorized into two groups: correlative and process-based or mechanistic models. Correlative models are also known as statistics models, habitat models, or ecological niche models (ENMs) that uses occurrence data and associated environmental layers of a study area to produce probability maps or relative environmental suitability for a species. Process-based, or mechanistic niche models, use species functional characteristics and physiological thresholds for model fitting (Coops *et al.*, 2009; Kearney and Porter, 2009). Notably, the correlative SDM uses existing species occurrence data from surveys and/ or online database for fitting of the model like MaxEnt (Elith and Leathwick, 2009).

Species distribution models can be generated using a variety of techniques, including DOMAIN (Carpenter *et al.*, 1993), BIOCLIM (Busby, 1991; Beaumont and Hughes, 2002), Genetic Algorithm for Rule Set Prediction (GARP) (Stockwell, 1999; Fitzpatrick *et al.*, 2007), Ecological Niche Factor Analysis (ENFA) (Hirzel *et al.*, 2002), Generalized Linear Model (GLM) and Generalized Additive Model (GAMs) (Elith *et al.*, 2006; Guisan *et al.*, 2006; Jensen *et al.*, 2008), and MaxEnt (Phillips *et al.*, 2006) and Ecological Niche Modeling (ENM) (Chalghaf *et al.*, 2016; Oliveira *et al.*, 2018).

The MaxEnt software is based on the maximum-entropy approach for modeling species niches and distributions. MaxEnt is very effective (Shankhwar *et al.*, 2019) and has a great advantage over the other species distribution models (SDMs). It is based on correlations between known presence records and environmental factors in a specific geographical area (Phillips *et al.*, 2006, Elith and Leathwick, 2009). Typically, multiple steps included in the development of SDM are: (i) the locations of occurrence of a species (or other phenomenon) are compiled; (ii) values of environmental predictor variables like climate at these locations are extracted from spatial database; (iii) the environmental values are used to fit a model to estimate similarity to the sites of occurrence, or another measure like species' abundance; and finally (iv) the model is used to predict the variable of interest across an interest region (and perhaps for a future or past climate).

Distribution of species could be ascertained through different modeling strategies that can be used to determine mapping (Phillips *et al.*, 2006). Remotely sensed data, such as satellite imaging and aerial photography, are critical for regional vegetation mapping, monitoring, and management. When map data is in digital format, GIS analysis techniques can be used to map, model, and compute statistics for vegetation types like invasive species (Madden, 2004). If the canopy is sufficiently dense and exhibits reflectance properties that are unique from native and other plants, satellite images can be used to efficiently map invasive alien woody plant species (Lamb and Brown, 2001). Remote sensing techniques have been used to map a variety of invasive species, including shrubs (Lawes and Wallace, 2006), perennials (Williams and Hunt, 2004), trees (Fuller and Harrison, 2005), and vines (Castro-Esau, 2006).

The SDM is widely used in macroecology, biogeography, and biodiversity research to model species geographic distributions, assessing the risk of species invasions, anticipating the effects of climate change on species distributions, and identifying conservation areas (Pearson, 2007; Araujo *et al.*, 2012). The SDMs produce maps of a species' environmental appropriateness, chance of a collection, and local occurrence (Miller, 2010). The applications of SDMs particularly MaxEnt in ecological and conservation research can be explained by the increasing availability of georeferenced species records (e.g., GBIF and Species Link), and environmental data (e.g., WorldClim, CliMond) on the web (Hijmans *et al.*, 2005; Kriticos *et al.*, 2012), as well as the user-friendliness. Thus, SDM tools can help design successful conservation and restoration management plans for such species by mapping possible distribution (Adhikari *et al.*, 2018).

5.3

SDMs for Managing Biodiversity Under Future Climates

Certainly, the development of SDMs has benefitted biodiversity conservation through their linkage of science to policy and decision processes. However, ecological systems face significant threats from climate change, and the need for effective responses is becoming a public policy in several jurisdictions (Hannah *et al.*, 2002; Stern, 2006; Sinclair *et al.*, 2010). The growing literature on the impact of climate change has amply revealed that climate change will force some species to shift their geographic ranges or face extinction (Massot *et al.*, 2008; Vos *et al.*, 2008). In such cases, species distribution modelling tools provide an important opportunity to map the past, current and future distribution pattern (Bhandari *et al.*, 2021). A large number of agencies and experts have increasingly started developing modeled projections of species distributions under likely climate scenarios so as to plan appropriate management and mitigation strategies. In this process, varied models have evolved to provide scenarios of different species under future landscapes based on known and projected environmental parameters. Proactive responses to ameliorate impacts are being proposed and they include species translocation and construction of dispersal routes to assist species to track shifting climates (Hoegh-Guldberg *et al.*, 2008; Phillips *et al.*, 2008; Sinclair *et al.*, 2010).

5.4

Rationale of the Present Study

Plant species are not randomly distributed in the landscape along environmental gradients, but display species specific tolerances shaping non-random assemblages (Pellissier *et al.*, 2013). The distribution of plants along environmental gradients is constrained by abiotic and biotic factors. Among biotic drivers, climate and soil properties have been recognized to strongly constraint the distribution of species (Dubuis *et al.*, 2013). Species are not an independent entity in an ecosystem, but they interact with sympatric species positively (e.g., facilitation, mutualism) and negatively (e.g., competitive exclusion, allelopathy) (Pellissier *et al.*, 2013). Thus, principles and reasons explaining the local assembly of communities need to integrate biotic processes. In the same way as abiotic variables influence and determine species distributions, biotic interactions and factors constrain ranges of individual species (Guisan and Rahbek, 2011; Wisz *et al.*, 2013). Despite the well-known significance of edaphic factors and habitat structure in plant growth and survival, both are often ignored in favor of climatic drivers when investigating the spatial patterns of plants species and diversity. Owing to ever-increasing availability of high-resolution climatic data, climate has always been the preferred environmental predictor set to explain spatial patterns of species diversity (Mod *et al.*, 2016; Chauvier *et al.*, 2021). Yet, especially in mountain ecosystems with complex topography, representing a wide array of vegetation zones, exhibiting greater habitat heterogeneity on account of micro-environmental variables (cumulative direct and indirect abiotic and biotic effects), missing edaphic and habitat components may be detrimental for a sound understanding of ecogeographic distribution of a species and other elements of biodiversity. Considering that mountain ecosystems represent natural laboratories for exploring effects of environmental variation on species distribution, the Himalayan State of Uttarakhand offers enormous opportunity for developing an insight on species range and distribution as a part of the present study.

The Chapter 1 has already highlighted the global trend of enhanced use of forest resources and a shrinking forest base, particularly of tropical forests in developing countries, ultimately threatening the sustainability of FGR and also stressed for urgent actions at different levels so as to ensure effective sustainable management and conservation of these resources. The CBD's Post-2020 Global Biodiversity Framework (GBF) has emphasized to arrest the decline and degradation of natural plant and animal populations including forestry species. The Chapter 3 has provided a detailed account of 250 prioritized FGR species in Uttarakhand and covered varied aspects *viz.*, confirming nomenclature, species use and threats, distribution of species in different forest divisions and forest types, and regeneration status. However, it lacks the vital information on ecogeographical range and species distribution. Keeping in view the importance of ecogeographical range in planning management strategies and implementation of conservation program, present study specifically aimed to generate much desired information on the range and species distribution of the targeted species across the altitudinal and environmental gradients in the Himalayan State.

5.5 Objectives

Following objectives were set forth for the present study relating to the ecogeographic mapping:

(i) Identify bioclimatic variables responsible for the occurrence and distribution of species.

(ii) Generate maps of ecogeographic distribution of prioritized FGR species specific to Uttarakhand.

(iii) Develop an insight on the extent and quality of forests available for conservation of prioritized species and status under legal PA coverage.

5.6 Material and Methods

The consultative process prioritized 50 FGR species for the purpose of developing an insight on their range and distribution adopting species niche modelling (Table 5.1). The details of methodology adopted for ecogeographic mapping using MaxEnt Modeling are diagrammatically presented in Fig. 5.1 and details on each step are elaborated below one by one.

Some of the prioritized species e.g., *Quercus semecarpifolia* and *Betula utilis* occur in patches instead of contiguous distribution. Hence, satellite imageries were used for identification and mapping forest patches of such species. Most of the other species neither had the contiguous distribution nor patchy distribution, instead they were highly scattered and occurred under the tree canopy cover of prominent species and, therefore, limited use of satellite imageries could be made in such cases. In such circumstances, the MaxEnt species distribution model was the best option to predict and prepare the eco-distribution maps of targeted species in Uttarakhand (Shankhwar *et al.*, 2019). Under SDM, two types of data were needed, i.e., species occurrence points (give precise location), and environmental, geographical and bio-climatic variables.

Table 5.1 : Prioritized FGR Species Selected for the Mapping of Ecogeographic Distribution

Sr. No.	Species	Sr. No.	Species
1.	*Abies spectabilis*	26.	*Juniperus polycarpos*
2.	*Acer ceasium*	27.	*Litsea glutinosa*
3.	*Albizia julibrissin*	28.	*Machilus gamblei*
4.	*Albizia odoratissima*	29.	*Madhuca longifolia*
5.	*Alnus nepalensis*	30.	*Myrica esculenta*
6.	*Betula utilis*	31.	*Olea europaea* subsp. *cuspidata*
7.	*Bombax ceiba*	32.	*Oroxylum indicum*
8.	*Boswellia serrata*	33.	*Ougeinia oojeinensis*
9.	*Buchanania cochinchinensis*	34.	*Phanera retusa*
10.	*Buxus wallichiana*	35.	*Pittosporum napaulense*
11.	*Carallia brachiata*	36.	*Populus ciliata*
12.	*Carpinus viminea*	37.	*Premna mollissima*
13.	*Cinnamomum tamala*	38.	*Prunus cerasoides*
14.	*Cochlospermum religiosum*	39.	*Pterospermum acerifolium*
15.	*Cornus capitata*	40.	*Quercus glauca*
16.	*Corylus jacquemontii*	41.	*Quercus lanata*
17.	*Diospyros montana*	42.	*Quercus semecarpifolia*
18.	*Diploknema butyracea*	43.	*Rhododendron arboreum*
19.	*Elaeodendron glaucum*	44.	*Semecarpus anacardium*
20.	*Ficus neriifolia*	45.	*Stereospermum chelonoides*
21.	*Flacourtia jangomas*	46.	*Taxus wallichiana*
22.	*Fraxinus micrantha*	47.	*Terminalia chebula*
23.	*Hovenia dulcis*	48.	*Trema orientalis*
24.	*Hymenodictyon orixense*	49.	*Tsuga dumosa*
25.	*Juglans regia*	50.	*Ulmus wallichiana*

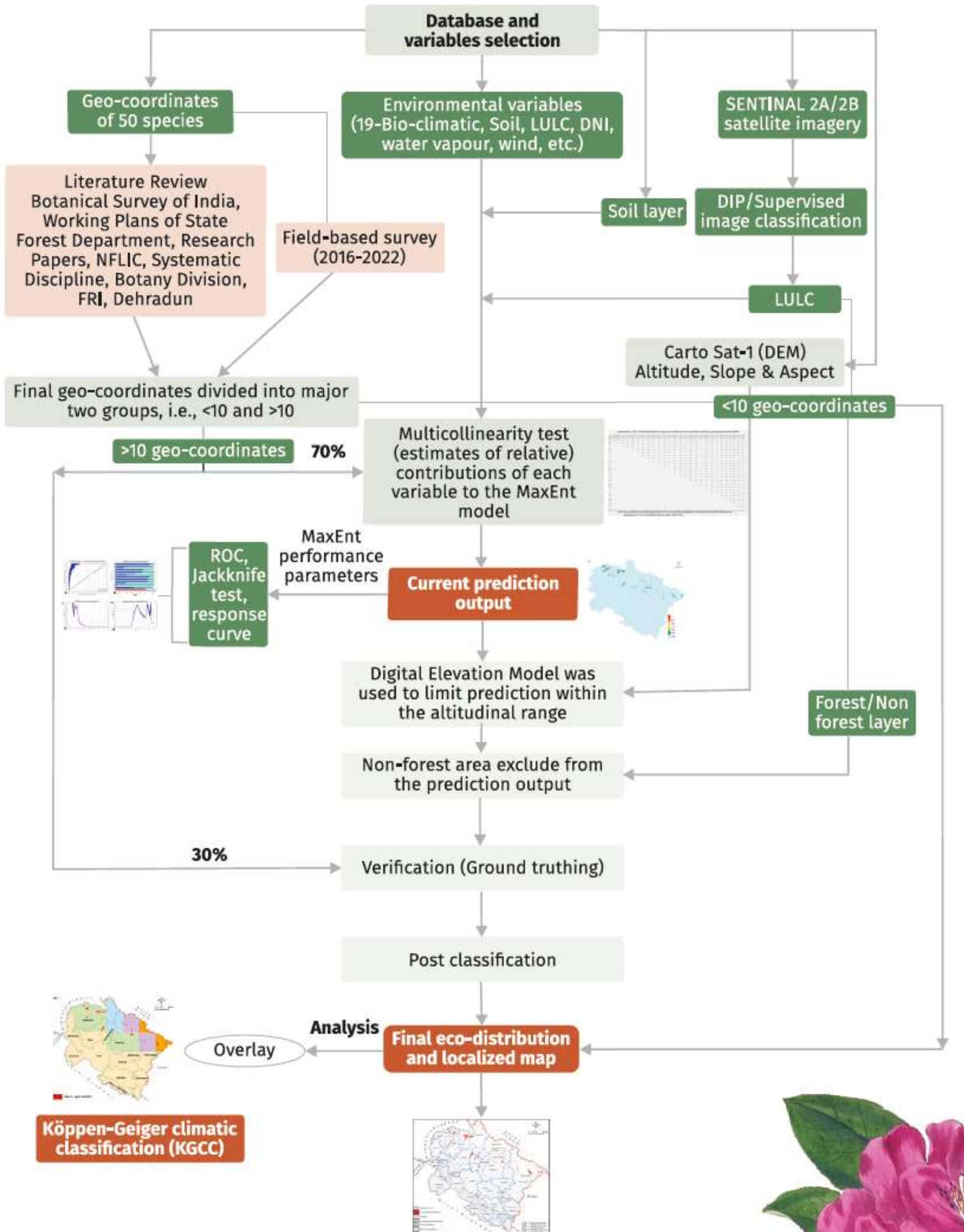


Fig. 5.1 : Adopted Methodology of Ecogeographic Mapping Based on MaxEnt Modeling

Conservation of Forest Genetic Resources

National Program for Conservation and Development of Forest Genetic Resources

Pilot Project

5.6.1

Review of Existing Information

The forest type map of Uttarakhand and forest cover in each district of the State as per the ISFR, 2011 (FSI, 2011) and various Working Plans, Wildlife/ PA Management Plans, and Tiger Conservation Plans of different FDs/ PAs/ TRs in the State of Uttarakhand were consulted and reviewed to develop an insight about the distribution status of targeted species. In addition, the data related to species associations and distribution were also gathered from the varied available documents in the NFLIC, FRI, WII, and the North-Western Regional Station of BSI. The research papers on 50 targeted FGR species were also reviewed to check the distribution as well as present status of each species.

5.6.2

Field Studies and Use of GIS Technology

The entire extent of the State of Uttarakhand formed the study area with an elevation ranging from 148-7,808 m. After collecting all the relevant and essential information regarding the occurrence of forest tree species, extensive field surveys were conducted during the period of 2016-2022, where multi-phase random sampling methodology was applied. Sampling followed linear transects of 300 m, where at least one tree was present, and a width of 50 m was considered for each transect, following the method adopted in ISFR 2011 (FSI, 2011). Subsequently, geospatial parameters, such as latitude, longitude and altitude, were recorded using GARMIN Oregon 750 model Global Positioning System (GPS) handheld device in the degree-decimal format with a positional accuracy of 5-8 m.

Accordingly, varying number of quadrats (10 m x 10 m) ranging from minimum of two to maximum of 68 quadrats in case of 37 prioritized FGR species were laid down in different forest areas with a minimum distance of 100 m maintained between two quadrats depending upon the occurrence of species. Altogether, 575 quadrats were laid in the field surveyed areas for 37 species. Additionally, in case of the each of the 37 species, a minimum of 30 geo-coordinates were also recorded wherever these species were found present. For the remaining 13 species having neither contiguous nor patchy distribution, GPS based geo-coordinates were recorded based on their sampling occurrence and observations during the field exploration. In the case of 13 species, the quadrat methodology could not be followed. In addition to the collection of data from the natural forests, geo-coordinates were also recorded for the scattered trees grown in the agricultural lands, pastures, and along the roadside. The non-biased sampling generally provides the potentially accurate picture of species distributions with minimum errors (Rocchini *et al.*, 2011). A minimum of 15 geo-coordinates was recorded for species taken into consideration for MaxEnt-based (Ver.3.4.4) SDM approach.

For precise species distribution mapping, boundaries of individual trees and patches were demarcated in polygons through GPS. The recorded parameters were converted into point shapefile and transformed into Keyhole Markup Language (KML), which was further used in Google Earth Pro for visible interpretation at the Forest-Informatics Laboratory, FRI. The actual occurrence area of a species was computed through 1 km buffer generated from the recorded geo-coordinates by using software ArcGIS (Ver.9.2). The predictive mapping and the probability distribution of the species were carried out through the MaxEnt model. Out of the well-distributed geo-coordinates, on an average ~70 per cent were used for estimating and predicting the distribution, and rest ~30 per cent for validation of the model output.

5.6.3

Satellite Data for Land Use and Land Cover (LULC)

The SENTINAL-2A/2B satellite imagery was download (Table 5.2) from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/) to generate LULC for seven classes, namely forest, settlement, agriculture, open land, barren land, snow cover, and water body.

Table 5.2 : Basic Information of Satellite Data Scenes of SENTINEL Downloaded from USGS for Uttarakhand

Sr. No.	Districts Covered Per Scene	Tile Number	Acquired Date (Date/ Month/ Year)	Platform	Map Projection/ Unit	UTM Zone
1.	Almora, Bageshwar, Chamoli, Rudraprayag, and Uttarkashi	T44RLU T44RLV	02/10/2021 11/07/2020	SENTINEL-2B, SENTINEL-2A	UTM, Meter	44
2.	Almora, Pithoragarh, and Champawat	T44RMT, T44RMU	12/25/2020 11/07/2020	SENTINEL-2B, SENTINEL-2A	UTM, Meter	44
3.	Almora, Champawat, Nainital, and Udham Singh Nagar	T44RLT	12/07/2021	SENTINEL-2B	UTM, Meter	44
4.	Dehra Dun, Haridwar, Pauri, Rudraprayag, Tehri, and Uttarkashi	T44RKU, T43RGP, T43RGQ	01/19/2021 12/25/2020 01/14/2021	SENTINEL-2A, SENTINEL-2B	UTM, Meter	44

5.6.4

Bioclimatic or Environmental Variables

Bioclimatic variables are derived from the monthly temperature and rainfall values to generate more biologically meaningful variables. These are often used in SDMs and related ecological modeling techniques. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation), and extreme or limiting environmental factors (e.g., temperature of the coldest or warmest month, and precipitation of the wet or dry quarters). A quarter is a period of three months (¼ of a year).

Different 19 bioclimatic variables representing annual trends, seasonality, and extreme environmental factors were derived from the monthly temperature and rainfall values provided in WorldClim (Ver.2.1, 1970–2000; http://www.worldclim.org/data/worldclim21.html) (Table 5.3). In the SDM, 19 bioclimatic variables and three other variables, such as direct normal irradiance (DNI), wind speed and water vapour with 30 arc-seconds resolution (~1 km^2 spatial resolution) of WorldClim (Ver.2.1) were used. In order to generate information on slope, aspect and altitude, the CartoSat-1 (Carto DEM Ver.3 R1) was downloaded from the website of ISRO Bhuvan (https://bhuvan-app3.nrsc.gov.in/data/download/). The soil data were derived from the India Dataset of Soil and Water Assessment Tool (SWAT; https://swat.tamu.edu/data/india-dataset/) (Table 5.3). The factors, *viz.*, DNI, slope, aspect, and altitude play a major role in controlling or regulating the distribution of a species, whose brief description is provided in Table 5.3.

Label	Variables	Scaling	Units Factor	Description
Bio 1	Annual Mean Temperature	10	°C	The yearly mean temperature is obtained by averaging the average temperature of each month over twelve months. An ecosystem's total energy inputs are approximated by its annual mean temperature.
Bio 2	Annual Mean Diurnal Range	10	°C	It is calculated as the average of the monthly temperature range (monthly maximum minus monthly minimum). This algorithm employs recorded temperature fluctuation within a month to capture the diurnal temperature range because the climatic data inputs are monthly or averaged over the months across numerous years. Calculating the temperature range for each day in a month and averaging these values for the month is theoretically similar to using monthly averages in this manner.
Bio 3	Iso-thermality [(Bio 2 / Bio 7) x 100]	100	°C	It measures the day-to-night temperature swings which differ from the summer-to-winter (annual) swings.
Bio 4	Temperature Seasonality (Std. Deviation x 100)	100	C of V	The degree of temperature fluctuation over a given year (or averaged years) based on the standard deviation (variance) of monthly temperature averages.
Bio 5	Maximum Temperature of Warmest Month	10	°C	It reveals a specific warm month in a year (time-series) or over the years (normal)
Bio 6	Minimum Temperature of Coldest Month	10	°C	It discloses specific cold months in a year (time-series) or over the years (normal).
Bio 7	Annual Temperature Range (Bio 5 - Bio 6)	10	°C	This is a metric measuring temperature fluctuation over time.

Table 5.3 : Bio-climatic Variables Used in the MaxEnt Model for Prediction Mapping

Label	Variables	Scaling	Units Factor	Description
Bio 8	Mean Temperature of Wettest Quarter	10	°C	This approximates the mean temperatures experienced throughout the wettest season in a year.
Bio 9	Mean Temperature of Driest Quarter	10	°C	It is a reasonable measure of the driest quarters in a year.
Bio 10	Mean Temperature of Warmest Quarter	10	°C	This is a fair estimate of the average temperatures during the warmest quarter.
Bio 11	Mean Temperature of Coldest Quarter	10	°C	This approximates the mean temperatures that prevailed during the coldest quarter.
Bio 12	Annual Precipitation	1	mm	The sum total of all monthly precipitation amounts.
Bio 13	Precipitation of Wettest Month	1	mm	It calculates the total precipitation for the wettest month.
Bio 14	Precipitation of Driest Month	1	mm	It occurs during the driest month.
Bio 15	Precipitation Seasonality [Coefficient of Variance (CV)]	100	C of V	This is a metric for the year-to-year variation in monthly precipitation totals. The standard deviation of monthly total precipitation to the mean monthly total precipitation (also known as the coefficient of variation) is indicated as a percentage in the index.
Bio 16	Precipitation of Wettest Quarter	1	mm	The statistic is a quarterly index that approximates total precipitation during the wettest quarter.
Bio 17	Precipitation of Driest Quarter	1	mm	It is a quarterly measure that approximates total precipitation during the driest quarter.
Bio 18	Precipitation of Warmest Quarter	1	mm	It falls during the warmest quarters.
Bio 19	Precipitation of Coldest Quarter	1	mm	It falls during the coldest quarter.
Alt	Altitude		m	It limits the distribution of a species within the preferable optimum elevational range.
Asp	Aspect		°	It is the orientation of a slope and determines the occurrence of species across the slope. A total of 10 classes of aspect, i.e., flat-(-1), north (0-22.5° and 337.5-360°), northeast (22.5-67.5°), east (67.5-112.5°), southeast (112.5-157.5°), south (157.5-202.5°), southwest (202.5-247.5°), west (247.5-292.5°) and northwest (292.5-337.5°) were considered (https://www.esri.com/arcgis-blog/products/product/mapping/aspect-slope-map/).
Slop	Slope		°	It measures the ground surface steepness and depicts the preferable slope for species distribution and it ranged from 0° to 45°

Label	Variables	Scaling	Units Factor	Description
DNI	Direct Normal Irradiance		W m^{-2}	It provides monthly average and annual average daily total solar resource, averaged over surface cells of 0.038 degrees in both latitude and longitude, or nominally 4 km in size. The DNI was downloaded from the Solar Energy Centre, Ministry of New and Renewable Energy (MNRE), GoI, New Delhi (https://maps.nrel.gov/ nsrdb-viewer/).
Vap	Vapor		mm	Primary form of atmospheric moisture
Wind	Wind		m s^{-1}	Wind speed is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature.
LULC	Land Use Land Cover			'Land use' refers to the way in which land has been used by humans, whereas 'Land cover' refers to the physical characteristics of Earth's surface.
Soil	Soil			Standard nomenclature of soil types used

5.6.5

Categorical Data (Forest Type Map and Forest Cover Map)

Categorical data is a sort of statistical data made up of categorical variables or data that has been converted to format like 'grouped data'. Categorical data can be derived from qualitative data observations that are summarized as counts or cross tabulations, or from quantitative data observations categorized within a given interval. A contingency table is frequently used to describe entirely categorical data. However, when it comes to data analysis, it's customary to use the word 'categories data' to refer to data sets that contain both categorical and non-categorical variables. For instance, Forest Type Map and Forest Cover Map (FTM and FCM) are the categorical data which contain the finite number of distinct groups, formulated on the basis of classification of forest types and forest canopy density classes, respectively. The FTM and FCM are generally divided into certain groups or classes. 'Forest type' are categorized into broad forest types of groups, such as *Shorea robusta* forest, *Pinus roxburghii* forest, Oak-pine, subalpine forest (*Betula utilis, Rhododendron campanulatum*), alpine forest, etc. Whereas, 'Forest cover' are categorized into forest and non-forest namely, river, water bodies, grasslands, scrub lands, settlements, etc., and the forest category is further characterized on the basis of forest canopy density classes *viz.*, VDF, MDF, and OF (see section 1.9.2.1). These categories are generally used in the field validation for mapping and accuracy assessment (Yang *et al.*, 2013; Rawat *et al.*, 2017). In India, 200 Forest Types (FT) were described by Champion and Seth (1968), and 178 of these were mapped (1: 50,000) by FSI using IRS 1D (LISS-III) satellite with the spatial resolution of 23.5 m × 23.5 m (FSI, 2011). The SENTINAL datasets were utilized to generate FCM and LULC. To match the spatial resolution of FTM and FCM with bioclimatic variables, categorical data layers were resampled (using nearest neighbor approach) according to the bioclimatic variable resolution (30 arc second).

5.6.5.1

Bioclimatic Predictor's Product Description and Codes

As stated above, the bioclimatic variables usually utilized in SDM are average monthly climate data for minimum, maximum, and mean of temperature and precipitation during 1970-2000, with 30 seconds (~1 km^2) resolution of the WorldClim (Ver. 2.1). These were based on O'Donnell and Ignizio (2012). Description of bioclimatic predictors has been furnished in Table 5.3.

5.6.6

Statistical Analysis

The multicollinearity test was conducted using the Pearson Correlation Coefficient (r) performed in software SPSS (Ver.16.0) to examine the cross-correlation among different bioclimatic variables. The variables with cross-correlation coefficient value greater than ±0.80 were excluded to delineate common variables. After that, suitable variables contributing to the biological characteristics of the species were selected and run in the MaxEnt model. This way, selected variables better represented species across the mountain State.

5.6.7

MaxEnt Model

The term MaxEnt stands for 'maximum entropy' modeling, predicts species occurrences by identifying the distribution that is most spread out, or nearest to uniform, while considering the limits of known bioclimatic variables. MaxEnt employs just presence data, and the algorithm compares the areas where a species has been discovered to all the environments available in the study region (Phillips *et al.*, 2006). In the description of results based on MaxEnt Model, a number of technical terms are being used. A brief description of prominent terms is presented in Table 5.4.

Table 5.4 : Prominent Terms Used in Application of MaxEnt Model

Terms	Description
AUC Curve	The 'Area under the receiver operating characteristic (ROC) curve' known as the AUC, is currently regarded as the gold standard for assessing the accuracy of predictive distribution models (Lobo *et al.*, 2008). According to the MaxEnt model, the geospatial data analysis uses threshold to make Binary prediction, with suitable conditions (habitat suitability) above the threshold (black line) and unsuitable below.
Response Curves	Response curves show the effect of each environmental variable in the MaxEnt prediction. The graphs reveal about the logistic prediction which varies as each environmental variable is changed while keeping all the other environmental factors constant. In other words, the curves reflect the marginal effect of changing only one variable, although the model may benefit from changing multiple variables at the same time.
Jackknife Test	The Jackknife test is a valuable priori measure for minimizing subjective uncertainty in bioclimatic layer selection. The test provides alternative estimates for which variables are most essential in the model, as well as a qualitative sense of the variables' independence. The Jackknife test gives training, test and AUC gains of three scenarios (without the variable, with only one variable, and with all the variables) for different bioclimatic variables used in the prediction modeling exercise (Phillips *et al.*, 2006; Stohlgren *et al.*, 2010).
Universal Transverse Mercator (UTM)	UTM is a map projection system for assigning coordinates to locations on the surface of the Earth. Like the traditional method of latitude and longitude, it is a horizontal position representation, which means it ignores altitude and treats the earth as a perfect ellipsoid. However, it differs from global latitude/ longitude in that it divides earth into 60 zones and projects each to the plane as a basis for its coordinates. Specifying a location means specifying the zone and the x, y coordinate in that plane. The projection from spheroid to a UTM zone is some parameterization of the transverse Mercator projection. The parameters vary by nation or region or mapping system (https://en.wikipedia.org/wiki/Universal_Transverse_Mercator).
Köppen-Geiger Climate Classification (KGCC)	The KGCC system is a commonly used vegetation-based climatic classification system developed by Wladimir Köppen in 1884. Later, the climatologist Rudolf Geiger introduced some changes to the classification system, which is thus sometimes called the Köppen-Geiger climate classification system. The KGCC is an attempt to devise a formula for delineating climatic borders in accordance with vegetation zones or biomes around the world. The system categories climates into five majors (3, 4, 9, 12, and 2 sub-groups in each major group), and a total of 30 subgroups, with each category subdivided based on seasonal precipitation and temperature trends. The five major groups are: A-Tropical Moist Climates (average temperature above 18°C in all months), B-Dry Climates (deficient precipitation for most of the year), C-Moist Mid-Latitude Climates with Mild Winters, D-Moist Mid-Latitude Climates with Cold Winters, and E-Polar Climates (extremely cold summers and winters) (Beck *et al.*, 2018; Cui *et al.*, 2021).

Model based on the maximum entropy approach was used for estimating the distribution and habitat suitability of a species with a set of 27 variables in the program MaxEnt. The model uses parameters, such as species geo-coordinates, environmental variables and categorical variables, which were allowed to run for 100 replicates for prediction mapping (Flory *et al.*, 2012). A total of 70 per cent well-distributed geo-coordinates were used for training and the rest 30 per cent for validation. The maximum number of background points was 10,000 and linear or quadratic or hinge features were used. In order to reduce model overfitting and over-prediction, regularization multiplier value was set to 0.1 (Phillips *et al.*, 2004) with 5,000 iterations and rest of the values were kept as default (Flory *et al.*, 2012; Yang *et al.*, 2013; Young and Carr, 2015).

Further, accuracy of the probability distribution was enhanced through masking the non-forest area and the over-predicted areas by using FCM and elevation layer over the model output. The performances of MaxEnt model were evaluated by AUC whose values ranged from 0 to 1, and model with the highest AUC value was considered as the best performer. The categorized models with values >0.9 were highly accurate for prediction modeling (Swets, 1988). The AUC provides a single measure of model performance independent of any particular choice of threshold. In addition, MaxEnt model output (generated prediction map) accuracy assessment was done through Kappa coefficient (K), Normalized Mutual Information (NMI) n(s) and True Skill Statistic (TSS), which were derived from the confusion matrix (Fielding and Bell, 1997; Allouche *et al.*, 2006). The MaxEnt model also provides the response curves and the Jackknife test to examine the importance of individual bioclimatic variables for prediction.

Furthermore, output maps appeared in WGS-84 projection, which has 'degree' as a unit. The software ArcGIS was used to convert 'degree' into 'meter' and re-projected the prediction output into UTM projection system with Zone-44 (UTM projection system uses 'meter' unit to calculate the distance and area). Once the transformation was complete, a raster calculator was used to determine the area under the prediction output. The potential species distribution map had a probability range between 0 and 1, which were re-grouped into four classes of potential habitats, i.e., 'high potential' (>0.6), 'good potential' (0.4–0.6), 'moderate potential' (0.2-0.4) and 'least potential' (<0.2) (Yang *et al.*, 2013).

Additionally, those predicted areas which did not fall within the range of a particular species, the minimum and maximum altitudinal distribution range was eliminated. Similarly, in an exercise conducted with forest/ non-forest area layer, for those species predicted area that did not fall within a green area (forest area) and fall outside the forest area, such as agriculture field, open land, barren land, snow cover and waterbody were also excluded. In the final step, remaining ~30 per cent, geo-coordinates were used to validate the MaxEnt model output map. Based on the limit of a prediction threshold, i.e., ~80 per cent of the tested geo-coordinates remains falls on the actual mapped area after validation, final maps of the 37 species were generated.

Current distribution was again overlaid on the KGCC system (Kottek *et al.*, 2006). The world map of KGCC classification was observed using Climatic Research Unit Gridded Time Series (CRU TS 2.1), temperature and Global Precipitation Climatology Centre (GPCC Full v4), which was freely available for download in GIS-based ESRI Shape file format (http://koeppen-geiger.vu-wien.ac.at/shifts.htm). Climate classification was subset into the study area of species for further analysis.

In present study, the distribution analysis of 50 targeted FGR species were divided into 2 categories. First category comprises of 4,677 sampling sites spread over 37 species used to prepare the eco-distribution maps in accordance with the MaxEnt modeling technique. Due to the inadequacy in sample points collections, the 37 species were further divided into three classes, namely Class I (consists of >80 geo-coordinates for Most Abundantly Distributed Species), Class II (consists of Moderately Abundant Species with geo-coordinates ranged from 35 to <80), and Class III (consists of species having least prevalent geo-coordinates ranged between 10 and <35). However, the second category consists of remaining 13 species, geo-located and mapped according to the geo-coordinates <10.

5.7 Results

The results have been summarized in two parts as 37 species were mapped through MaxEnt-based prediction modeling, whereas remaining 13 species as per locations recorded during the field surveys.

5.7.1. Eco-Distribution Mapping of Thirty-Seven FGR Species

A total of 37 species belonging to 25 families were distributed across 23 forest sub-types in the Uttarakhand Himalayas according to MaxEnt-based modelling analysis (Table 5.5). Further, in FTM, forest sub-types such as 12/C1, 9/C1b, 12/C1e, 12/C1b, and 5B/C2 recorded maximum number of species, whereas 12/C1, 3C/C3a, 5/1S2, and 5/DS1 recorded lower number of species. The vastly distributed species in accordance with FTM were *Bombax ceiba* (Malvaceae), *Rhododendron arboreum*

(Ericaceae) and *Premna mollissima* (Lamiaceae) belonging mostly to the sub-tropical and sub-alpine climatic regimes. The unique species, namely *Hymenodictyon orixense* (Rubiaceae) and *Pterospermum acerifolium* (Malvaceae) belonged to sub-tropical climatic regions.

In the present study for all the 37 species, the predicted omission rate curve was observed above the threshold which revealed the habitat suitability (Young *et al.*, 2011; Castilho, 2015; Phillips, 2017).

5.7.1.1

Class-I (>80 Geo-coordinates)

This class holds a total of 11 species with altitudinal variation ranged from 203 m to 3,653 m. According to the FTM, these 11 species were distributed in 14/C1a, 14/C1b, 12/C1a, 9/C1b, 3C/C2a, 3C/C2c, 5B/C2, 9/C1a, 5B/C1a, 12/C1e, 12/C1b, 12/C1f, 12/C2c, 3C/C3a, 3C/Ds1, 5B/C1a, 5B/C1b, 5/1S2,12 /C1, 12 /C2c, 12 /C2a and 15/C1 forest sub-types (Plate 5.1 to 5.11). The MaxEnt modeling performance was evaluated using AUC, which varied from 0.800±0.105 (*Ougeinia oojeinensis*) to 0.969±0.040 (*Quercus lanata*) for prediction mapping. The value of classification accuracy measures, namely, *K* ranged from 0.195 (*O. oojeinensis*) to 0.595 (*Q. lanata*) while TSS varied from 0.687 (*O. oojeinensis*) to 1.788 (*Taxus wallichiana*). Notably, while validating the ground-based tested datasets, maximum points have fallen in the prediction threshold with 92.59 per cent accuracy for *Myrica esculenta* and minimum (80.25 per cent) for *Bombax ceiba*. The environmental variables, namely, Soil, Bio 1, Bio 2, Bio 6, Bio 7, Bio 8, Bio 9, Bio 14, Bio 19, Vap, Wind, Alt and Slop showed highest contribution in predicting the distribution of 11 species (Table 5.5; Plate 5.1 to 5.11).

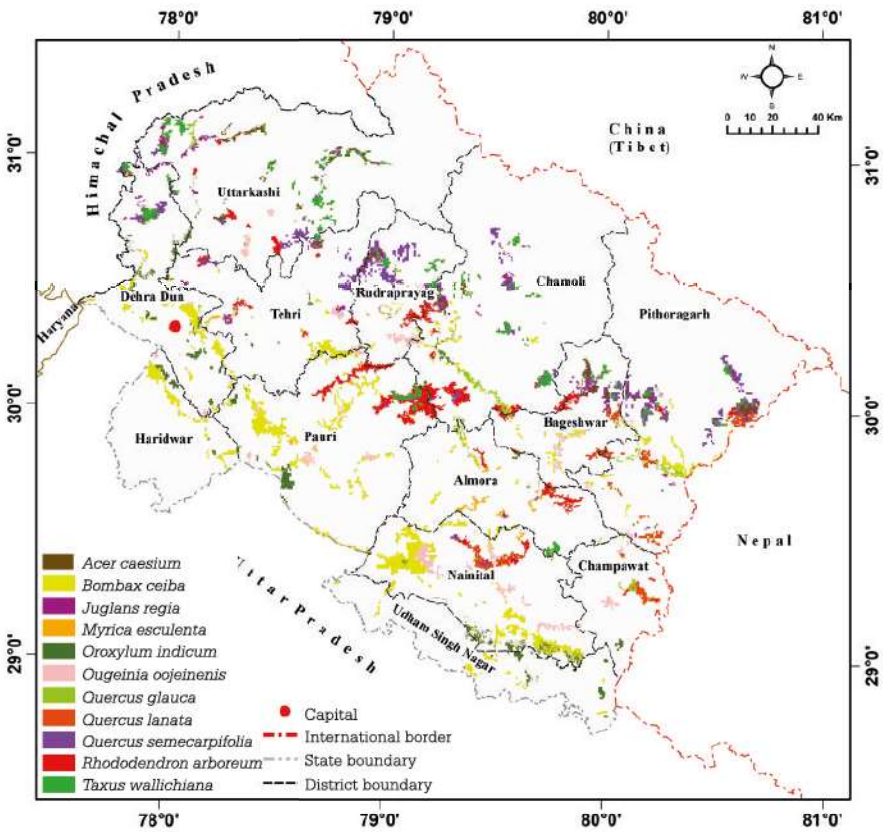


Fig. 5.2 : Mapping of Ecogeographic Distribution of Eleven Species Having >80 Geo-coordinates

The ecogeographic distribution maps revealed an estimated area of 4,603.55 km^2 for 11 species, which was 8.62 per cent of the total geographical area and 18.98 per cent of the total forest cover and 19.10 per cent of the protected areas (PAs) (Table 5.5); with maximum occurrence under PAs were recorded for *A. caesium* (33.07 per cent) and minimum for *M. esculenta* (0.75 per cent). Additionally, the areas under VDF, MDF and OF estimated were 958.44 km^2, 2,529.43 km^2 and 1,113.69 km^2, respectively. Notably, maximum (MDF=512 km^2) and minimum (VDF=12.19 km^2) values were recorded for *Q. semecarpifolia* and *Q. lanata*, respectively, specifically in Chamoli, Pithoragarh, Nainital, and Uttarkashi districts. The KGCC revealed occurrence of these species in Cwb (C=warm temperate, w=winter dry, and b=warm summer) subtropical highland oceanic climate of upper zonation of middle Himalayas, and Cwa (C=warm temperate, w =winter dry, and a =hot summer) humid subtropical climate in lower stretches of middle Himalayas revealing its warmer and humid climatic conditions prevailed for maximum occurrence. Overall, *O. oojeinensis* dominated in this class with maximum values of accuracy estimators, *Q. semecarpifolia* for maximum estimated area, and Pithoragarh district for occurrence record to cover FTM (Fig. 5.2).

Myrica esculenta

Geographical Attributes

Altitude Range(m)	896–2,289
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Almora, Pauri, Nainital

Accuracy Measures

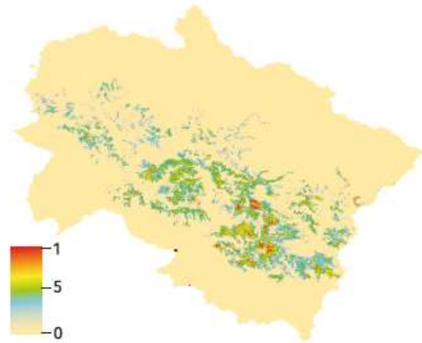
No. of Sample Points	800
AUC	0.927±0.025
Kappa	0.407
TSS	0.719
NMI	0.657
Environmental Variables	Vap, Bio 8

Area Occurrence

Estimated Area (km^2)	477.26
VDF (km^2)	111.17
MDF (km^2)	260.52
OF (km^2)	105.57
Total Forest Cover (%)	1.90
Total Geographical Area (%)	0.89

a

b



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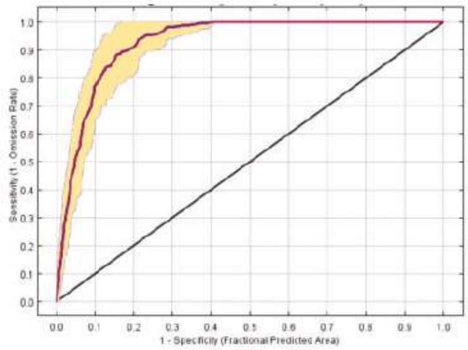

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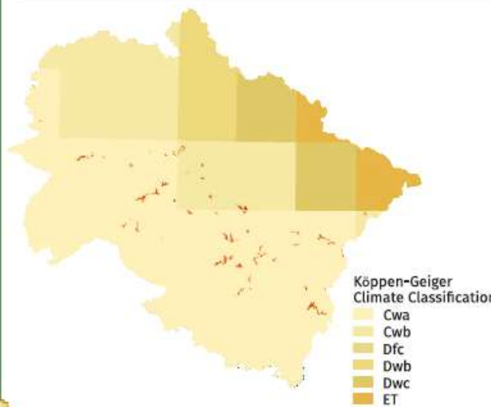

Plate 5.1
Eco-distribution of *Myrica esculenta*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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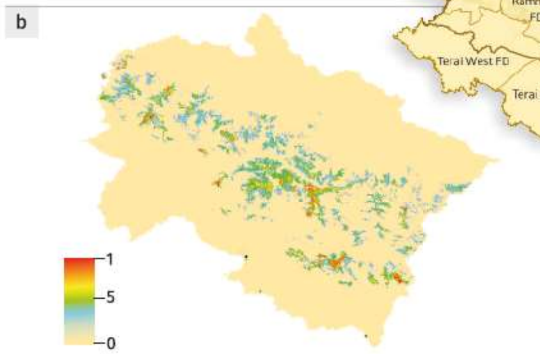
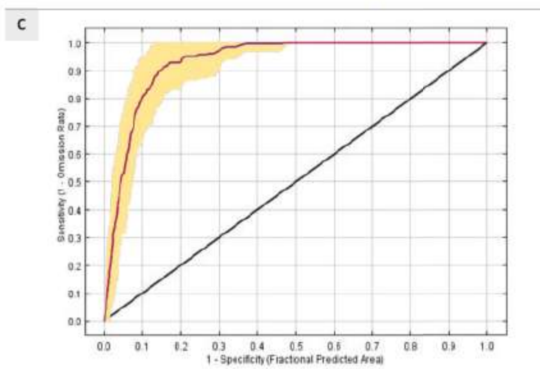
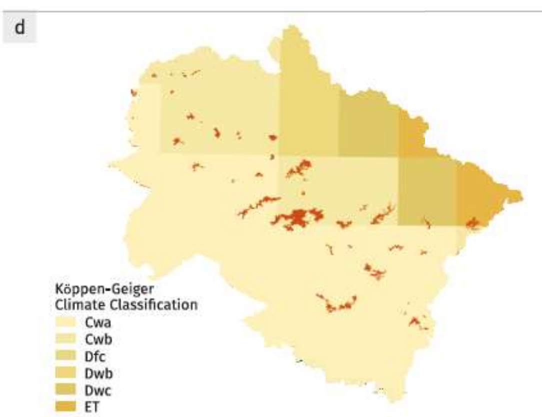
Myrica esculenta
District Boundary
Boundary of Forest Division/ Protected Area

Rhododendron arboreum
District Boundary
Boundary of Forest Division/ Protected Area

Rhododendron arboreum







0 25 50 100 Km

Plate 5.2
Eco-distribution of *Rhododendron arboreum*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range(m)	1,145-3,312
Forest Types	12/C1a, 12/C1e, 12/C2a, 12/C2b
Soil Texture	Loamy
Climatic Status	Sub-alpine
KGCC	Cwb
Maximum Species Occurrence	Champawat, Pauri

Accuracy Measures

No. of Sample Points	750
AUC	0.932±0.031
Kappa	0.409
TSS	0.744
NMI	0.625
Environmental Variables	Bio 7, Soil, Vap

Area Occurrence

Estimated Area (km²)	617.48
VDF (km²)	167.48
MDF (km²)	320.75
OF (km²)	129.25
Total Forest Cover (%)	2.54
Total Geographical Area (%)	1.15

Quercus semecarpifolia

Geographical Attributes

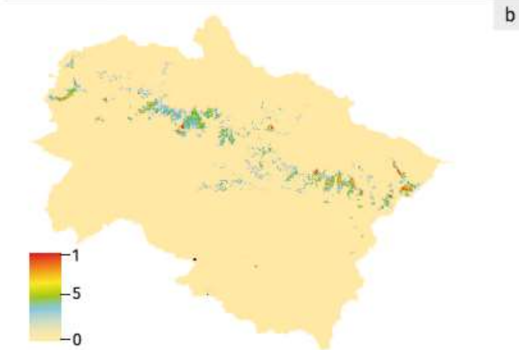
Altitude Range(m)	2,249-3,652
Forest Types	12/C2b, 12/C2c
Soil Texture	Loamy
Climatic Status	Sub-alpine
KGCC	Cwb
Maximum Species Occurrence	Chamoli, Pithoragarh

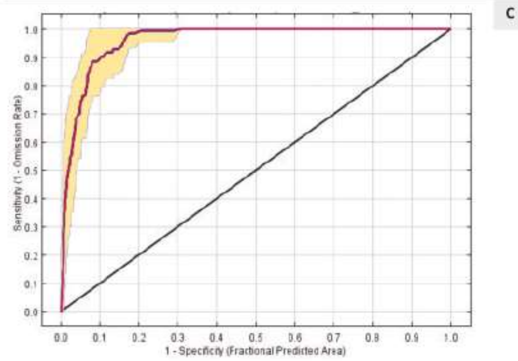
Accuracy Measures

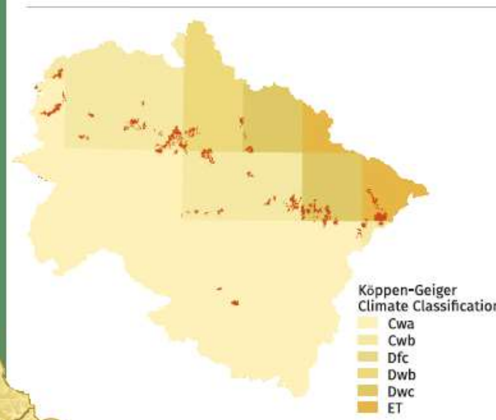
No. of Sample Points	589
AUC	0.961±0.018
Kappa	0.553
TSS	0.723
NMI	0.509
Environmental Variables	Bio 14, Bio 7

Area Occurrence

Estimated Area (km²)	832.4
VDF (km²)	214.15
MDF (km²)	512.47
OF (km²)	105.79
Total Forest Cover (%)	3.43
Total Geographical Area (%)	1.56







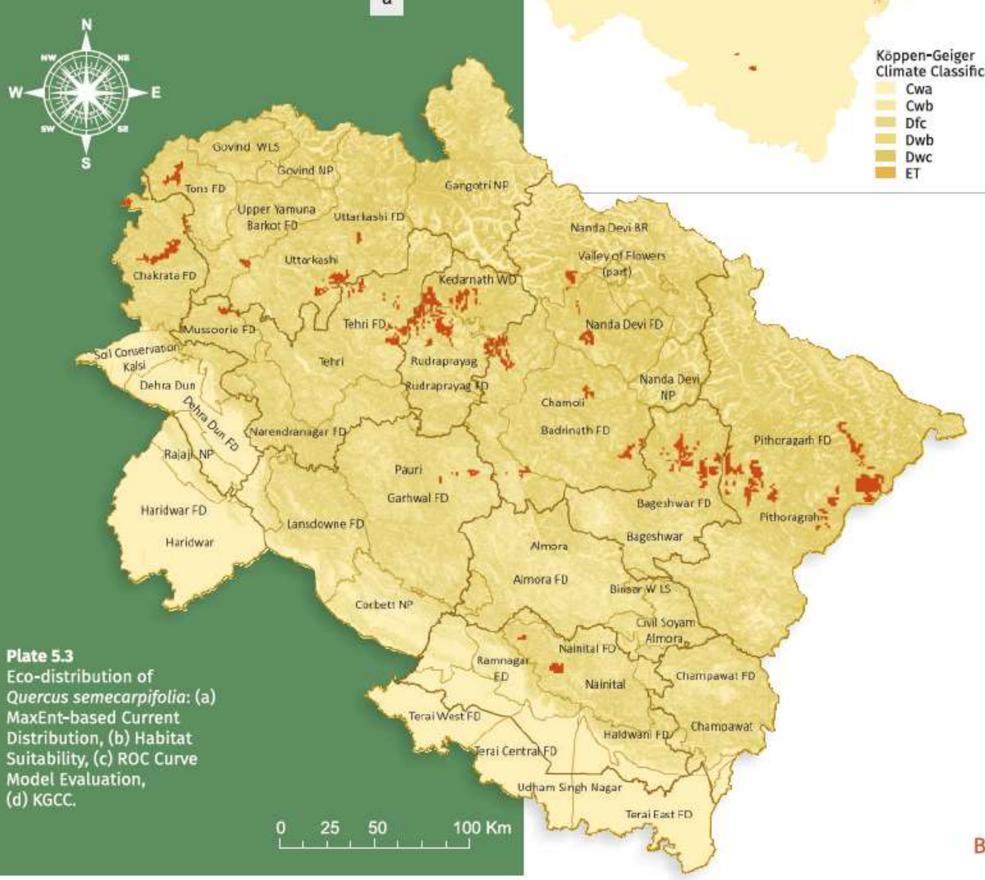


Plate 5.3
Eco-distribution of *Quercus semecarpifolia*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Bombax ceiba

Conservation of Forest Genetic Resources

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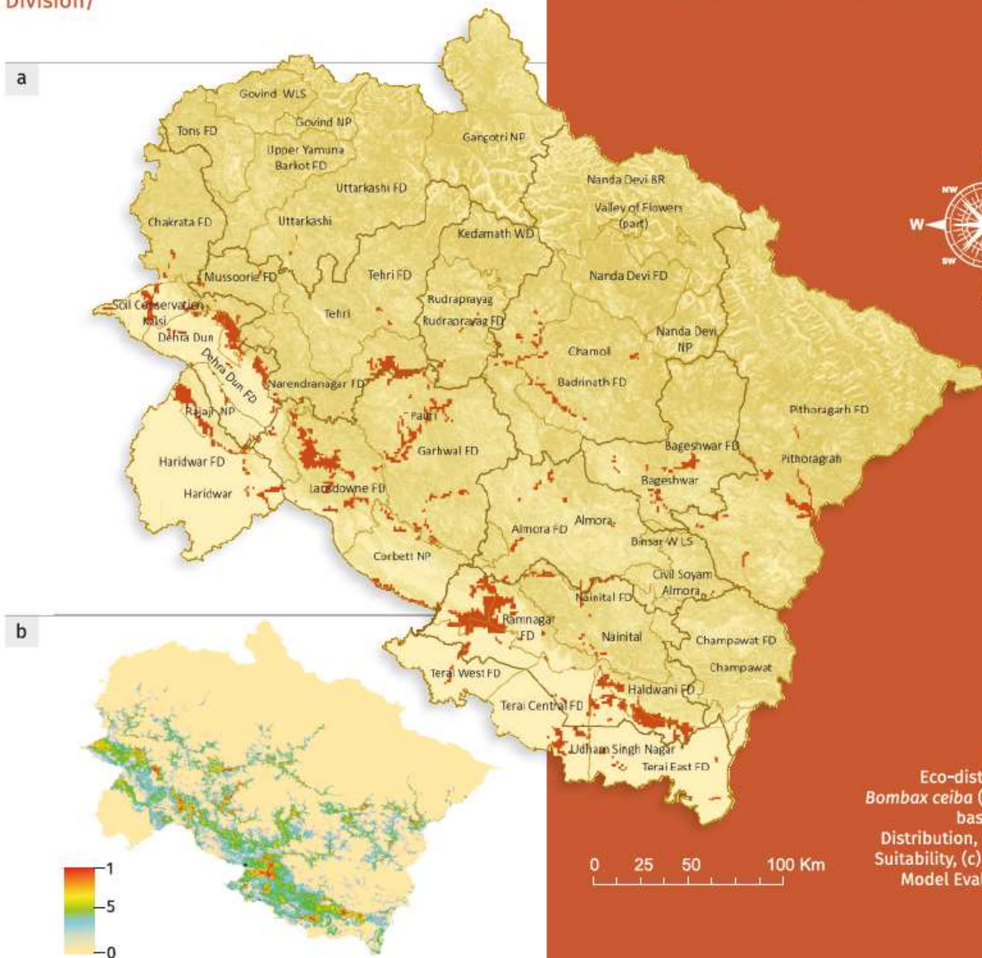
Uttarakhand State



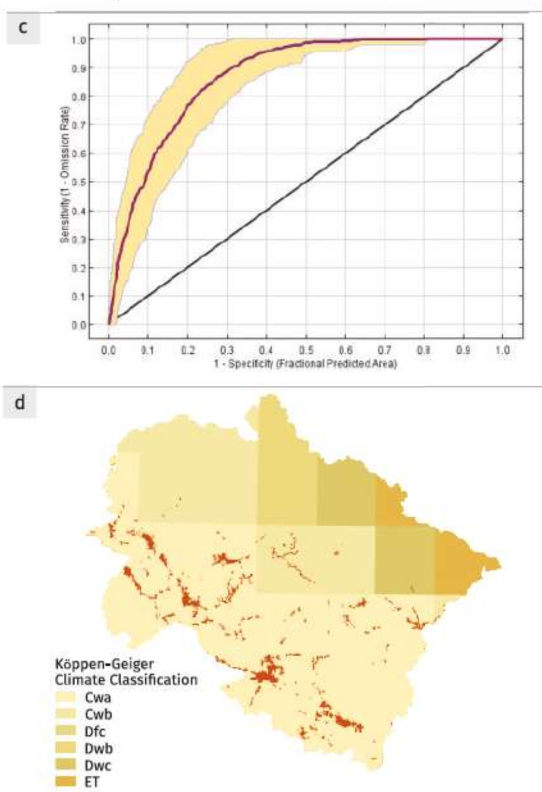


Plate 5.4 - Eco-distribution of *Bombax ceiba* (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range(m)	203-1,865
Forest Types	3C/C2a, 3C/C2c, 3C/C3a, 5B/C1a,
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwb
Maximum Species Occurrence	Nainital, Pauri

Accuracy Measures

No. of Sample Points	574
AUC	0.870±0.044
Kappa	0.346
TSS	0.727
NMI	0.740
Environmental Variables	Bio 9, Slop

Area Occurrence

Estimated Area (km^2)	716.9
VDF (km^2)	54.63
MDF (km^2)	355.68
OF (km^2)	306.59
Total Forest Cover (%)	2.95
Total Geographical Area (%)	1.34

Taxus wallichiana

Geographical Attributes

Altitude Range(m)	2,192–3,432
Forest Types	12/C1e, 12/C2b, 14/C1a
Soil Texture	Rock outcrops
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Chamoli

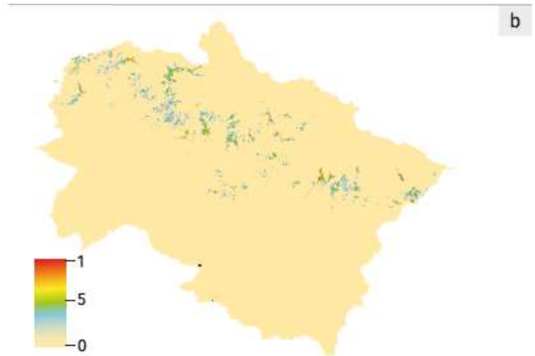
Accuracy Measures

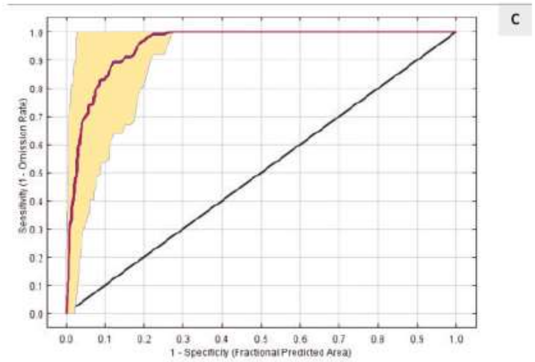
No. of Sample Points	365
AUC	0.952±0.046
Kappa	0.431
TSS	1.788
NMI	0.740
Environmental Variables	Bio 19, Soil

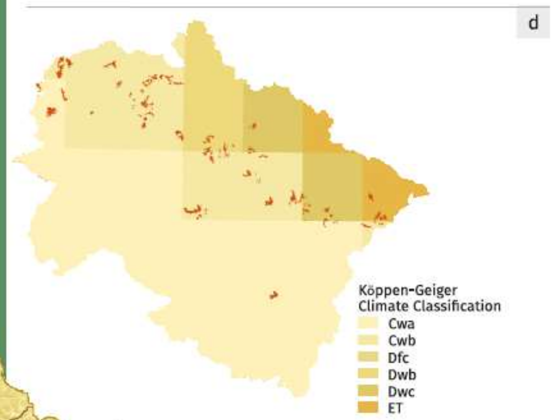
Area Occurrence

Estimated Area (km²)	545.86
VDF (km²)	147.99
MDF (km²)	336.58
OF (km²)	61.29
Total Forest Cover (%)	2.25
Total Geographical Area (%)	1.02

Plate 5.5
Eco-distribution of *Taxus wallichiana*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.







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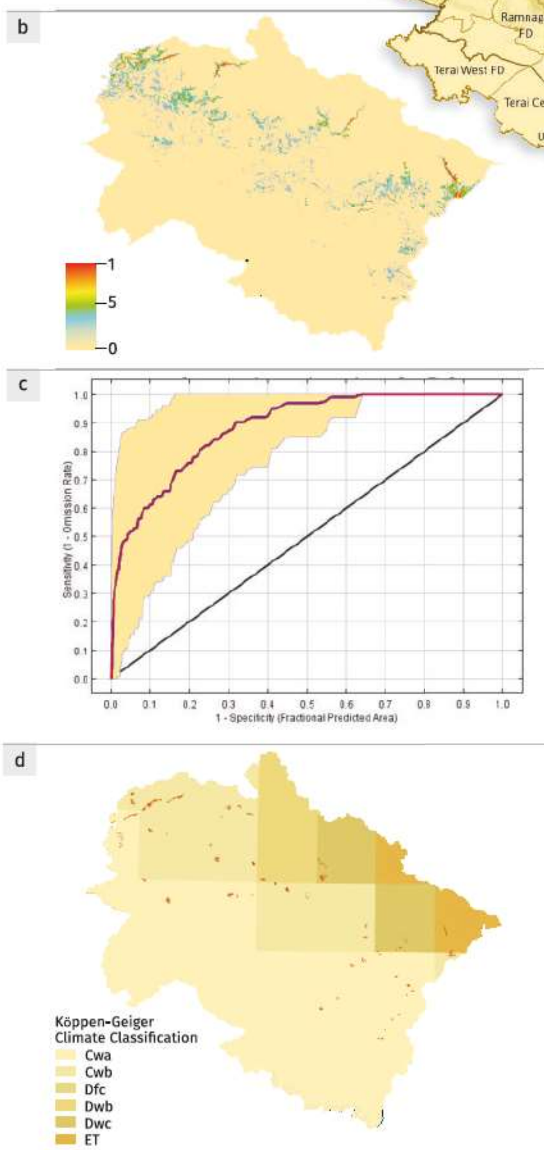
Taxus wallichiana
District Boundary
Boundary of Forest Division/ Protected Area

Juglans regia



Plat 5.6 – Eco-distribution of *Juglans regia*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Uttarakhand State

Geographical Attributes

Altitude Range(m)	1,275–2,987
Forest Types	12/C1, 12/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Pithoragarh

Accuracy Measures

No. of Sample Points	162
AUC	0.884±0.091
Kappa	0.432
TSS	0.705
NMI	0.566
Environmental Variables	Soil, Vap, Bio 1

Area Occurrence

Estimated Area (km²)	204.34
VDF (km²)	39.93
MDF (km²)	124.96
OF (km²)	39.45
Total Forest Cover (%)	0.84
Total Geographical Area (%)	0.38

Acer caesium

Geographical Attributes

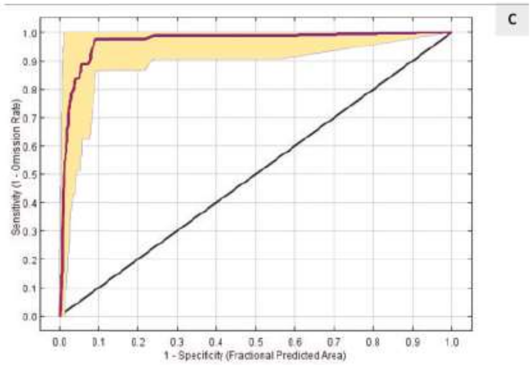
Altitude Range(m)	2,288–3,653
Forest Types	12/C1e, 12/C1f,
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Pithoragarh

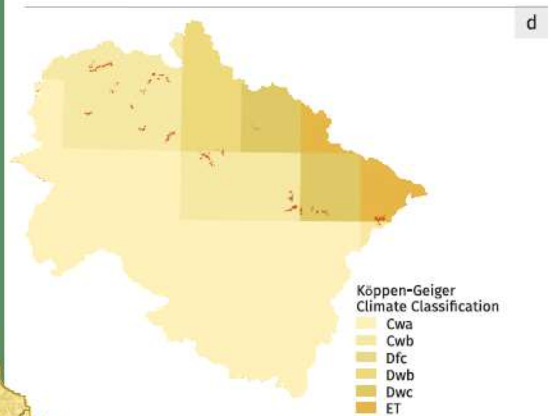
Accuracy Measures

No. of Sample Points	117
AUC	0.967±0.068
Kappa	0.512
TSS	0.853
NMI	0.400
Environmental Variables	Bio 1, Bio 6, Soil

Area Occurrence

Estimated Area (km^2)	183.97
VDF (km^2)	35.7
MDF (km^2)	122.91
OF (km^2)	25.36
Total Forest Cover (%)	0.76
Total Geographical Area (%)	0.34





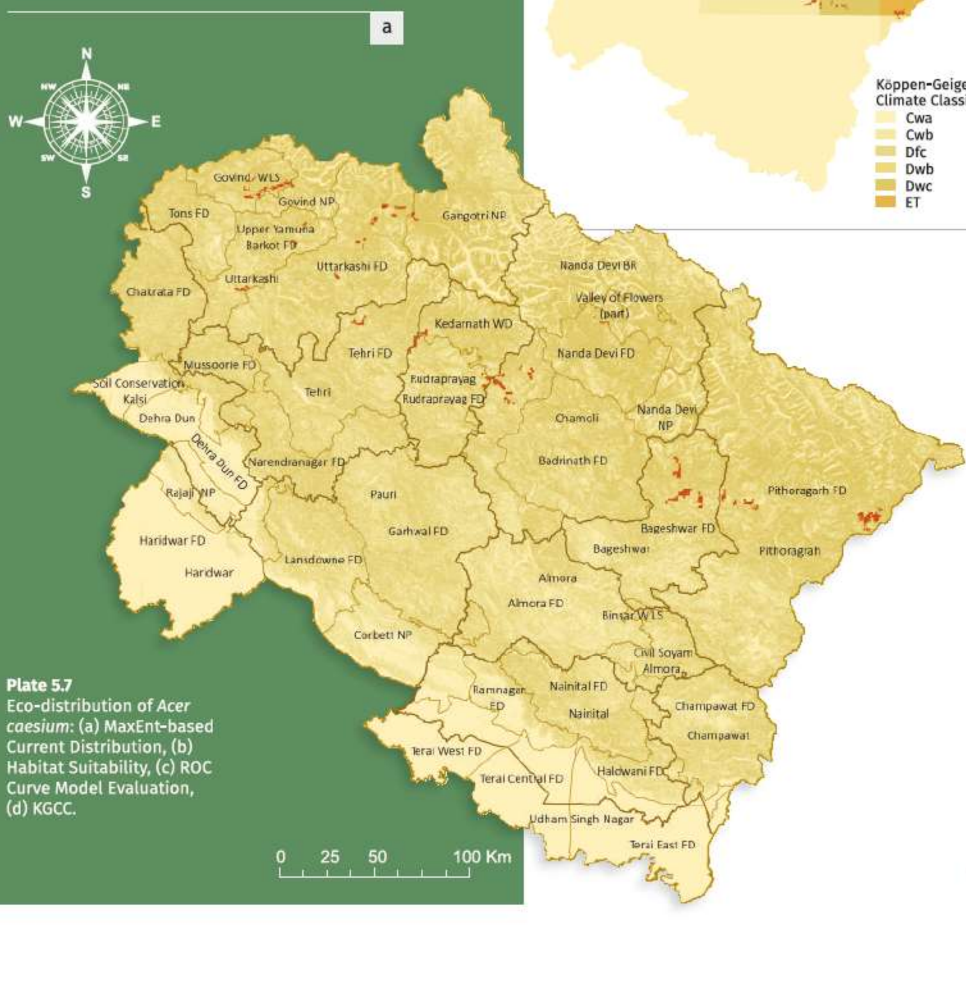


Plate 5.7
Eco-distribution of *Acer caesium*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Acer caesium
District Boundary
Boundary of Forest Division/ Protected Area

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National Program for Conservation and Development of Forest Genetic Resources

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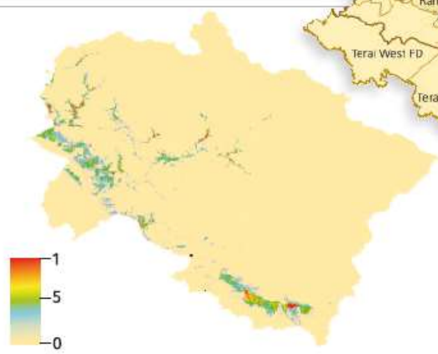
Oroxylum indicum
District Boundary
Boundary of Forest Division/ Protected Area

Oroxylum indicum

a

b



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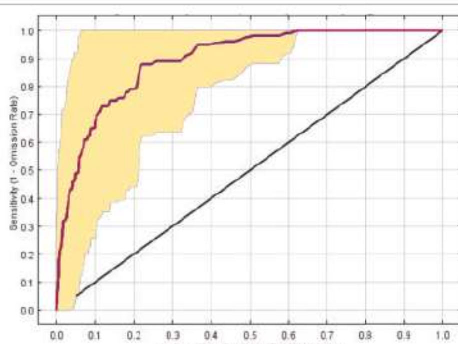

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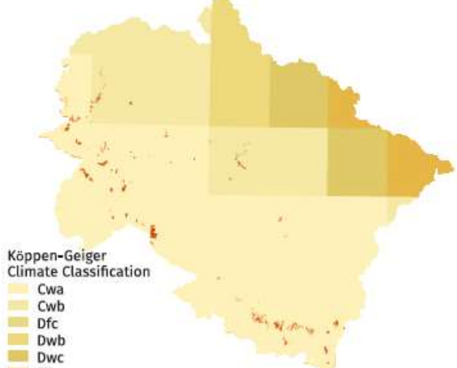

Plate 5.8 - Eco-distribution of *Oroxylum indicum*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Uttarakhand State

Geographical Attributes

Altitude Range(m)	207-1,690
Forest Types	5B/C1a, 5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Dehra Dun, Nainital

Accuracy Measures

No. of Sample Points	94
AUC	0.895±0.104
Kappa	0.247
TSS	0.736
NMI	0.247
Environmental Variables	Wind, Soil

Area Occurrence

Estimated Area (km²)	286.51
VDF (km²)	43.28
MDF (km²)	118.48
OF (km²)	132.75
Total Forest Cover (%)	1.17
Total Geographical Area (%)	0.53

Quercus glauca

Geographical Attributes

Altitude Range(m)	842–2,205
Forest Types	12/C1a, 12/C1e, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Chamoli, Pithoragarh

Accuracy Measures

No. of Sample Points	87
AUC	0.928±0.099
Kappa	0.420
TSS	0.769
NMI	0.468
Environmental Variables	Soil, Bio 1, Alt

Area Occurrence

Estimated Area (km^2)	184.26
VDF (km^2)	33.93
MDF (km^2)	96.77
OF (km^2)	53.56
Total Forest Cover (%)	0.76
Total Geographical Area (%)	0.34

a

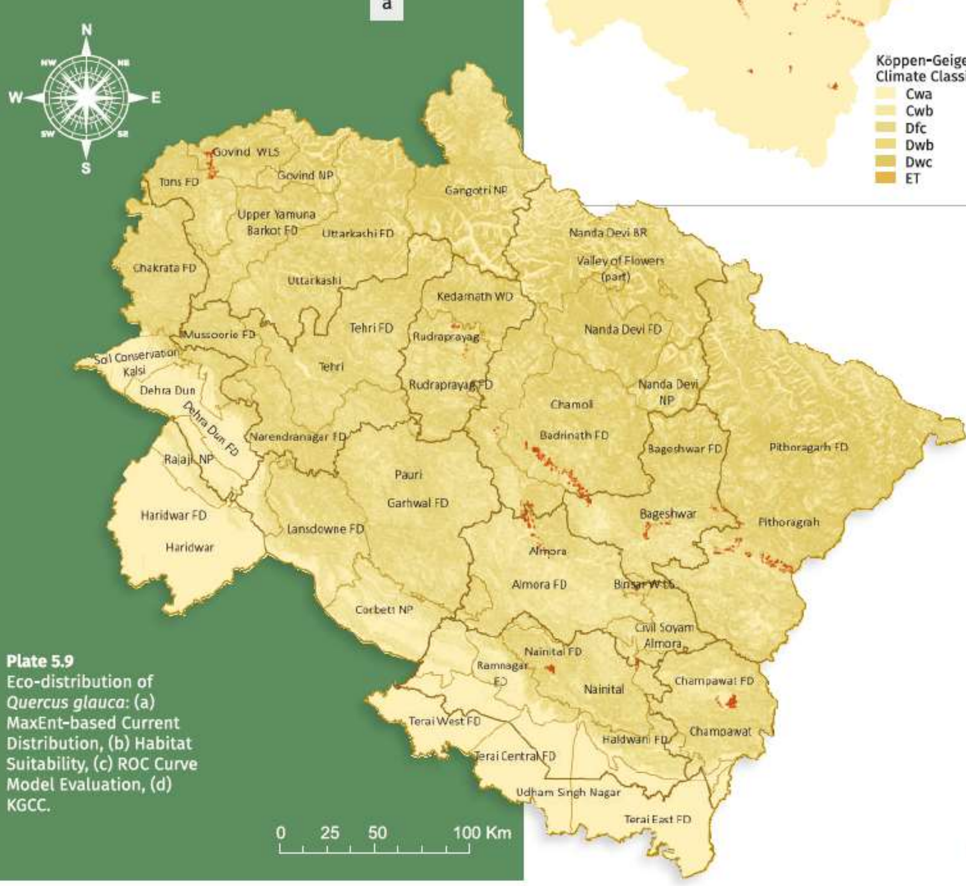
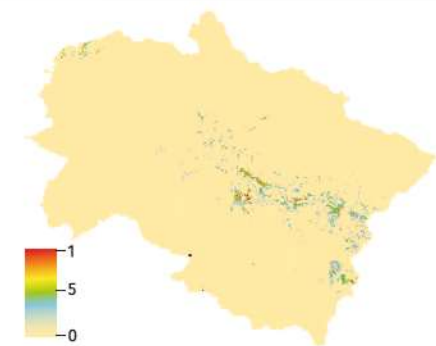


Plate 5.9
Eco-distribution of *Quercus glauca*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

b



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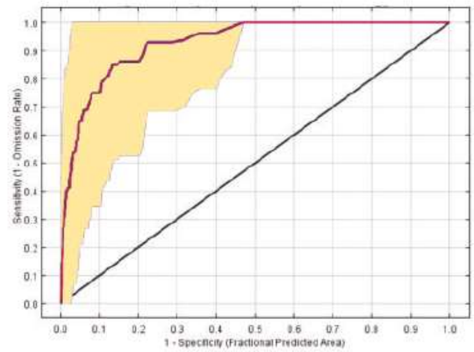

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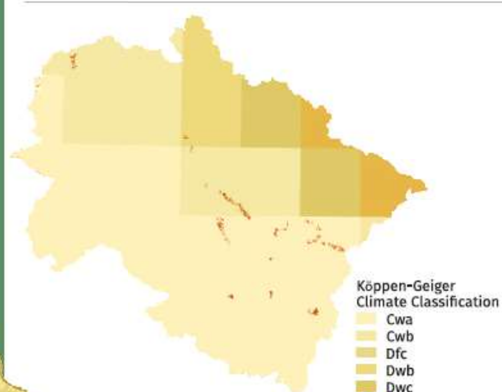
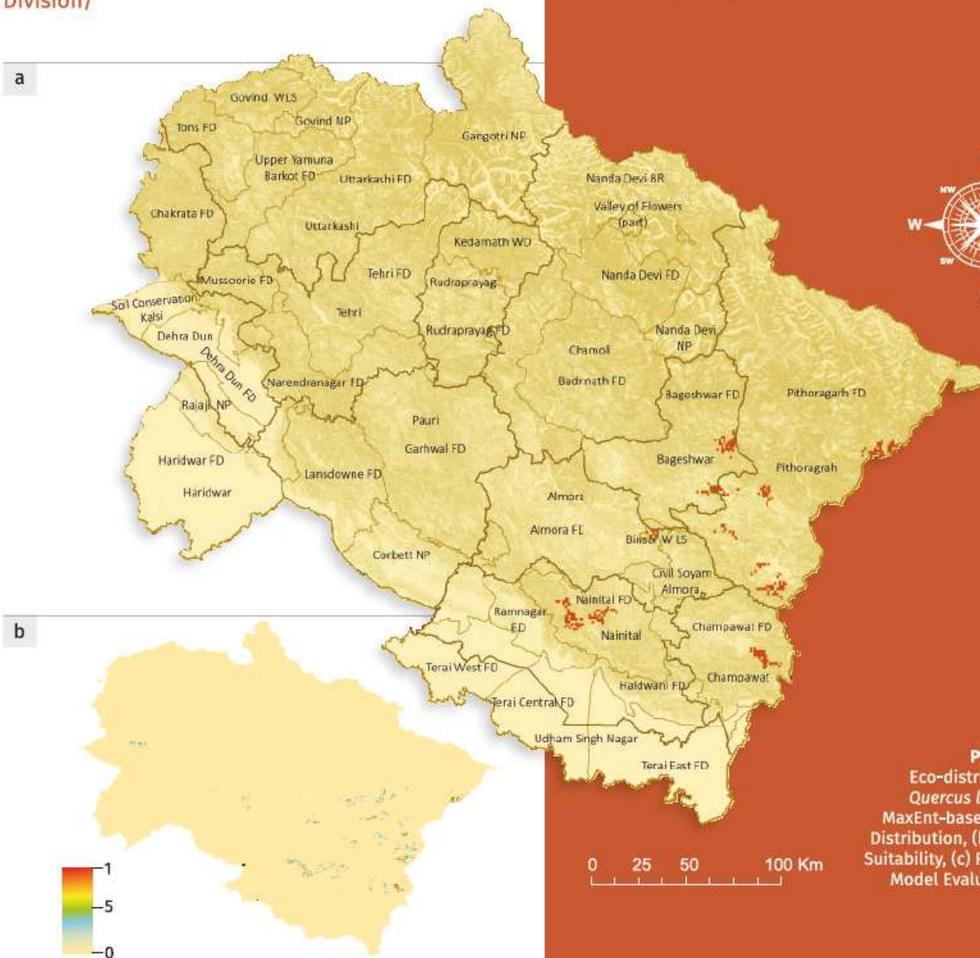


Quercus glauca
District Boundary
Boundary of Forest Division/ Protected Area

Quercus lanata
District Boundary
Boundary of Forest Division/ Protected Area

Quercus lanata

a



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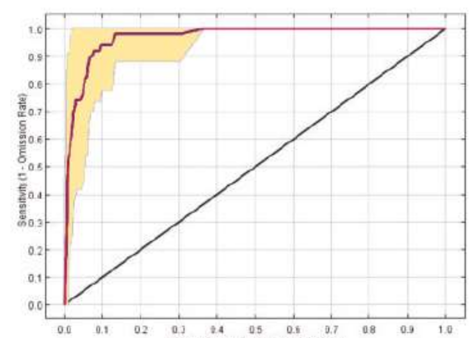

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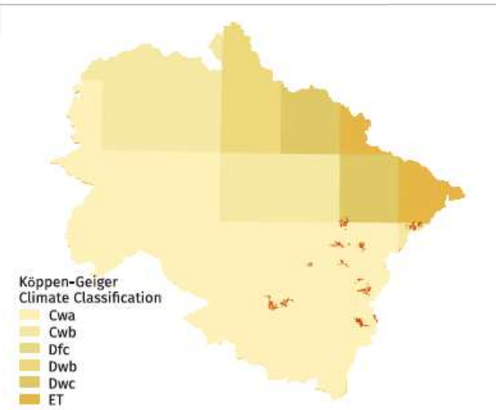

Plate 5.10 – Eco-distribution of *Quercus lanata*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range(m)	1,526-2,454
Forest Types	12/C1a, 12/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Pithoragarh, Nainital

Accuracy Measures

No. of Sample Points	83
AUC	0.969±0.040
Kappa	0.595
TSS	0.856
NMI	0.372
Environmental Variables	Soil, Vap, Alt

Area Occurrence

Estimated Area (km²)	169.84
VDF (km²)	50.47
MDF (km²)	85.91
OF (km²)	33.46
Total Forest Cover (%)	0.70
Total Geographical Area (%)	0.32

Ougeinia oojeinensis

Geographical Attributes

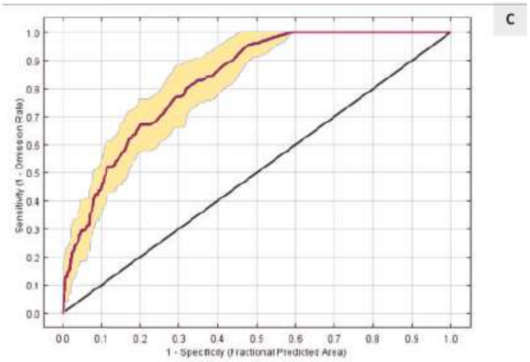
Altitude Range (m)	307–1,735
Forest Types	9/C1a, 5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Nainital, Bageshwar

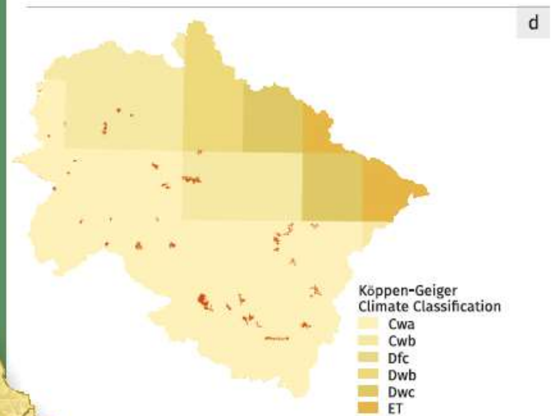
Accuracy Measures

No. of Sample Points	81
AUC	0.800±0.105
Kappa	0.195
TSS	0.687
NMI	0.693
Environmental Variables	Soil, Bio 2, Bio 1

Area Occurrence

Estimated Area (km²)	384.73
VDF (km²)	69.71
MDF (km²)	194.4
OF (km²)	120.62
Total Forest Cover (%)	1.58
Total Geographical Area (%)	0.72





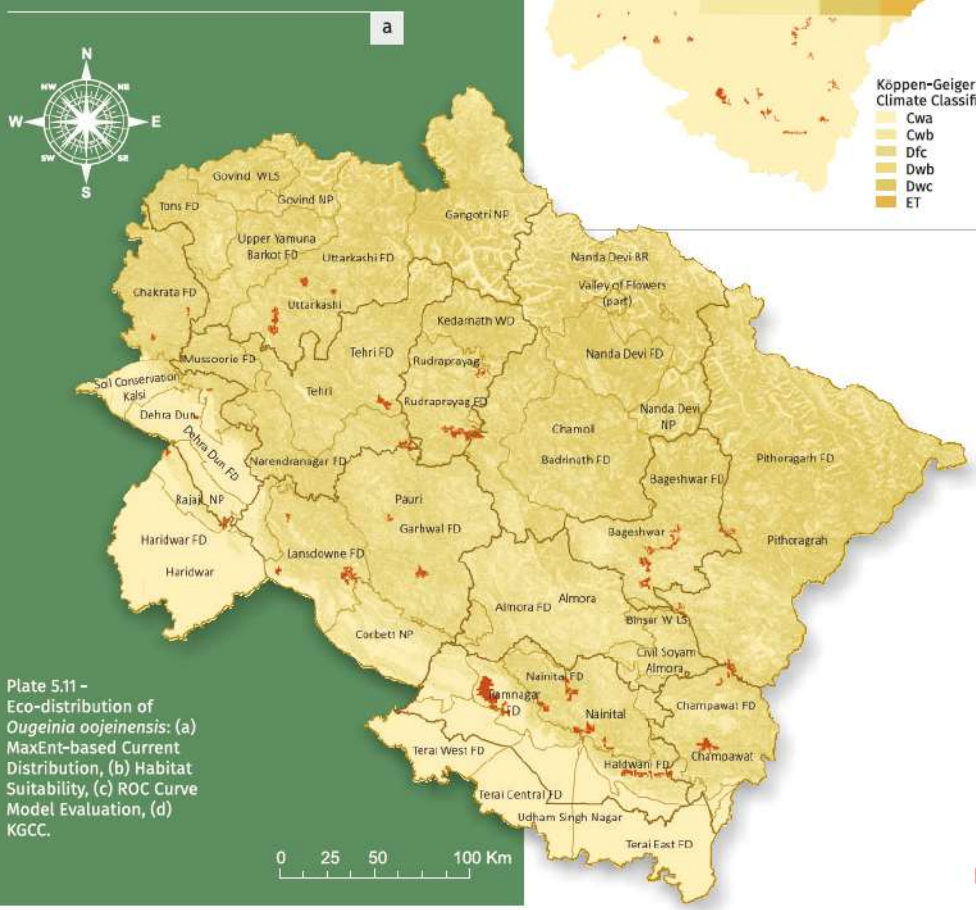


Plate 5.11 – Eco-distribution of *Ougeinia oojeinensis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Ougeinia oojeinensis
District Boundary
Boundary of Forest Division/ Protected Area

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5.7.1.2

Class-II (35–80 Geo-coordinates)

This class holds a total of 12 species with altitude ranging from 329 m to 3,806 m. According to the FTM, Class-II species were distributed in 12/C2b, 14/C1a, 14/C1b, 12/C1a, 12/C1b, 12/C1e, 9/C1b, 12/C2c, 9/C1b, 12/C1f, 3C/C2a, 5B/C1a, 5B/C2b, 5B/C2, 3C/C3a, 5B/C1a, 5B/C1b, 9/C1b, 12/C1d, 12/2S1 and b, 16/C1 forest sub-types (Plate 5.12 to 5.23). In case of these 12 species, the values of AUC varied from 0.843±0.177 (*Terminalia chebula*) to 0.989±0.010 (*Hovenia dulcis*), *K* from 0.200 (*Semecarpus anacardium*) to 0.719 (*Abies spectabilis*), and TSS from 0.703 (*Cinnamomum tamala*) to 0.901 (*H. orixense*). For precise validation, maximum 91.15 per cent of ground-based tested points have fallen in the prediction threshold for *B. utilis*, whereas minimum (77.27 per cent) teste points were recorded in case of *T. chebula* and *S. anacardium*. The environmental variables, namely, Soil, Bio 1, Bio 4, Bio 5, Bio 6, Bio 8, Bio 10, Bio 14, Bio 15, LULC, altitude and water vapor showed highest contribution in predicting the distribution of 12 species (Table 5.5; Plate 5.12 to 5.23).

The ecogeographic distribution maps revealed an actual estimated area of 2,401 km^2 for 12 species, which was 4.49 per cent of the total geographical area and 9.88 per cent of the total forest cover and 33.61 per cent of the PAs (Plate 5.12 to 5.23). Notably, maximum and minimum occurrence under PAs were noted for *B. utilis* (92.93 per cent), and *P. cerasoides* (2.89 per cent), respectively. The areas under VDF, MDF, and OF estimated were 549.43 km^2, 1,409.42 km^2 and 438.84 km^2, respectively. Interestingly, maximum (MDF=241.14 km^2), and minimum (VDF=11.75 km^2) values were recorded for *Betula utilis* in Uttarkashi and Pithoragarh districts, respectively. The ecogeographic distribution map showed maximum occurrence of these species in Cwb (C=warm temperate, w=winter dry, and b=warm summer) subtropical highland oceanic climate of upper zonation of middle Himalayas and Cwa (C=warm temperate, w=winter dry, and a=hot summer) humid subtropical climate in lower stretches of middle Himalayas. Overall, *H. dulcis* dominated in this class with maximum values of accuracy estimators, *B. utilis* for maximum estimated area, and Uttarkashi district for occurrence record to cover FTM (Fig. 5.3).

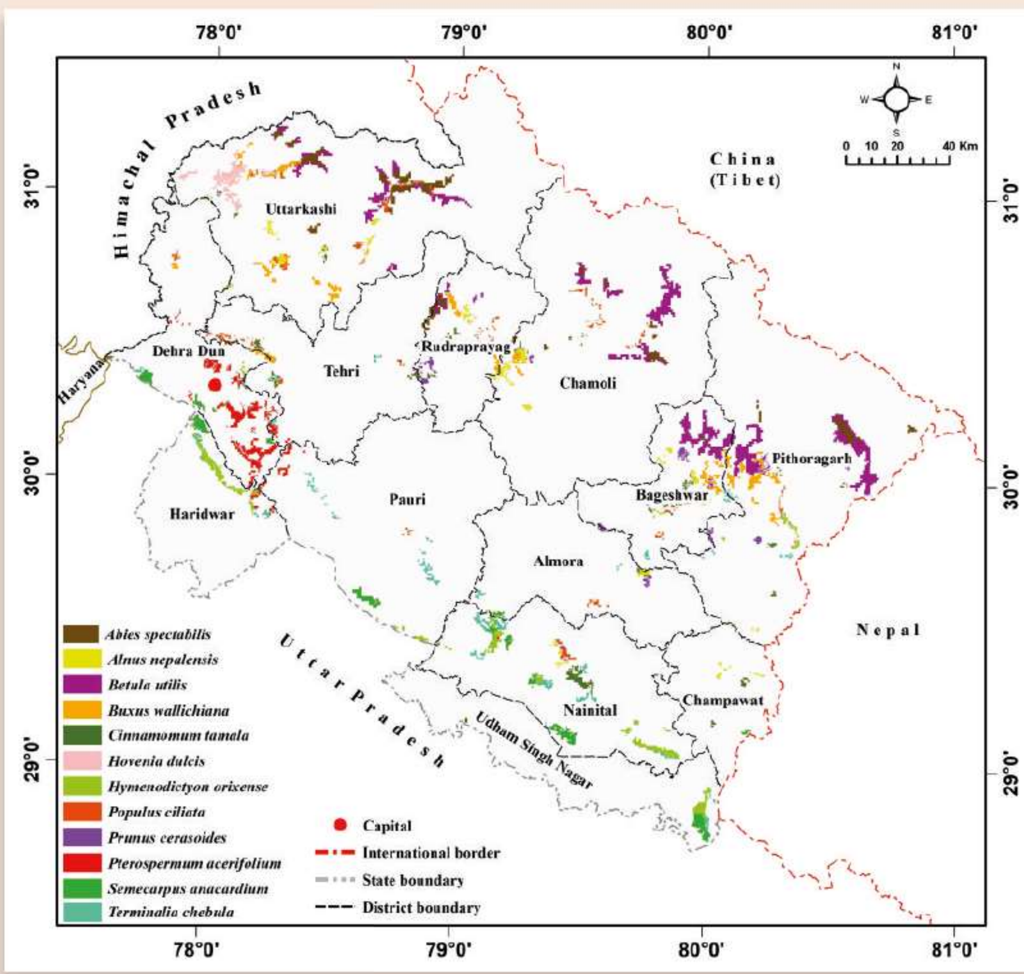

Fig. 5.3 Mapping of Ecogeographic Distribution of Twelve Species Having Geo-coordinates Ranged from >35 to <80

Pterospermum acerifolium

Geographical Attributes

Altitude Range (m)	329–1,076
Forest Types	3C/C2a
Soil Texture	Loamy skeletal
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Dehradun, Pauri

Accuracy Measures

No. of Sample Points	79
AUC	0.986±0.041
Kappa	0.508
TSS	0.794
NMI	0.403
Environmental Variables	Bio 14, Vap, Alt

Area Occurrence

Estimated Area (km²)	217.55
VDF (km²)	74.96
MDF (km²)	97.97
OF (km²)	44.62
Total Forest Cover (%)	0.90
Total Geographical Area (%)	0.41

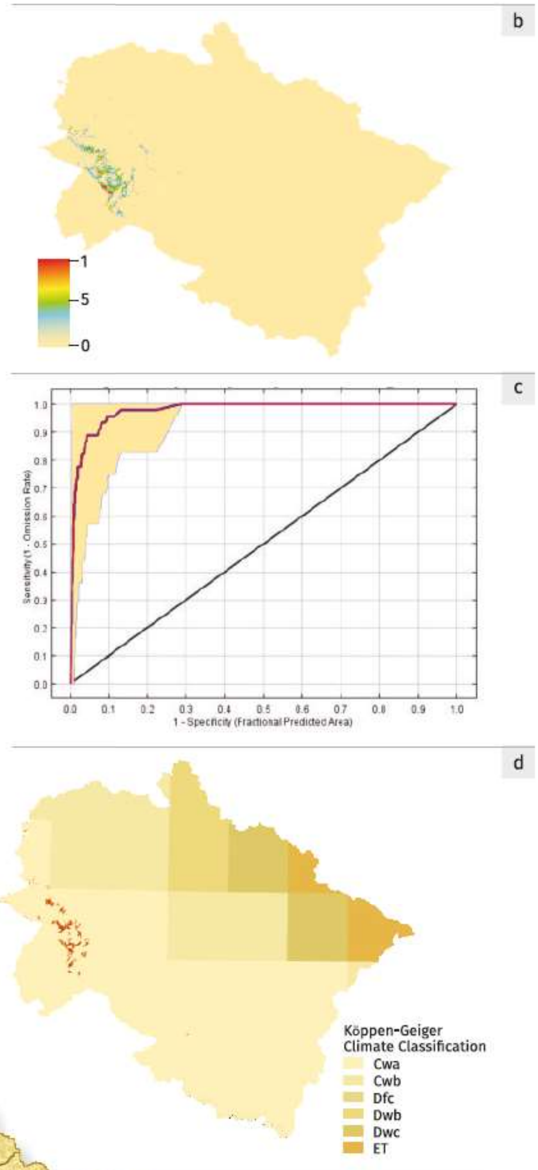

Plate 5.12
Eco-distribution of *Pterospermum acerifolium*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Pterospermum acerifolium
District Boundary
Boundary of Forest Division/ Protected Area

Betula utilis

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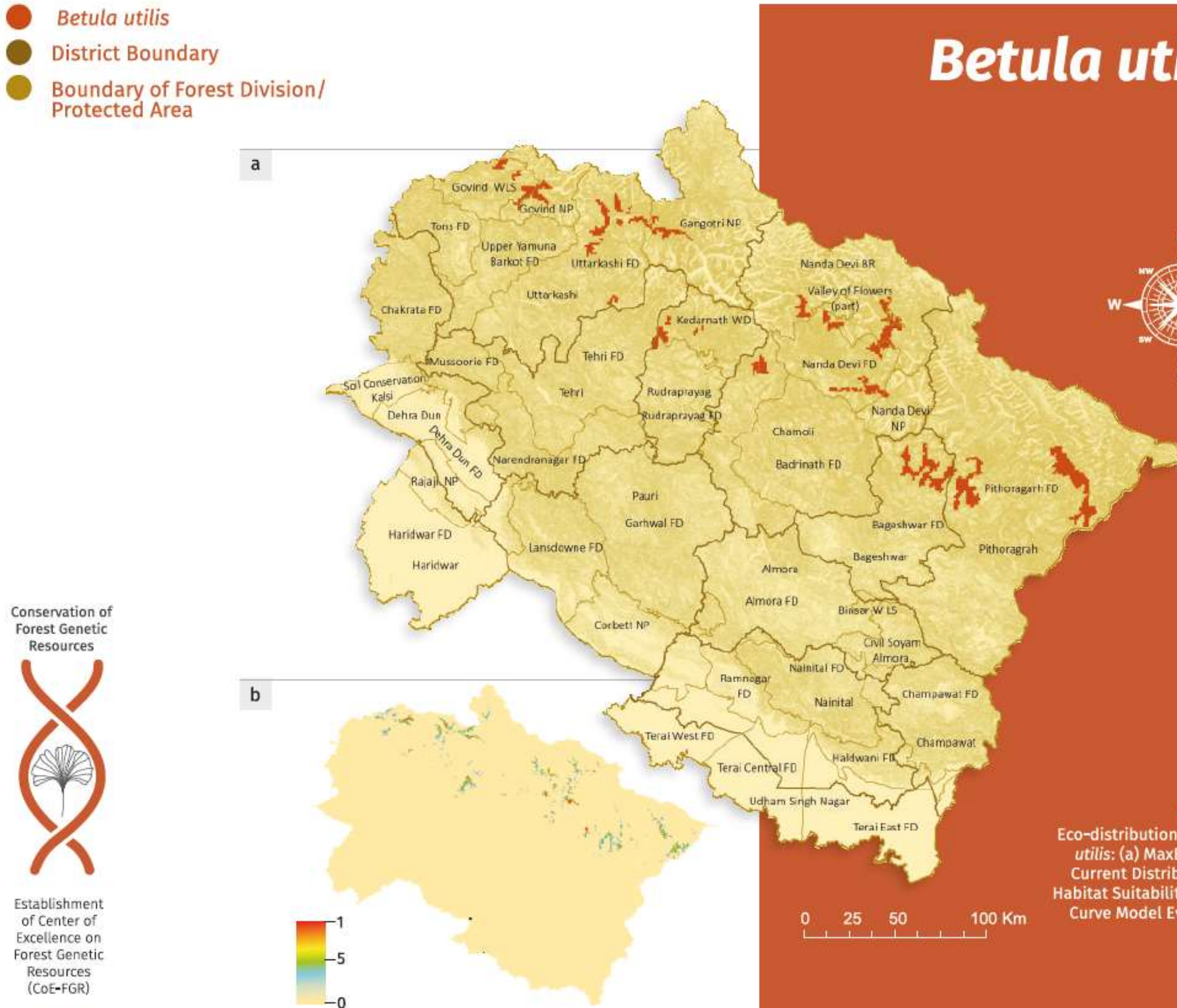
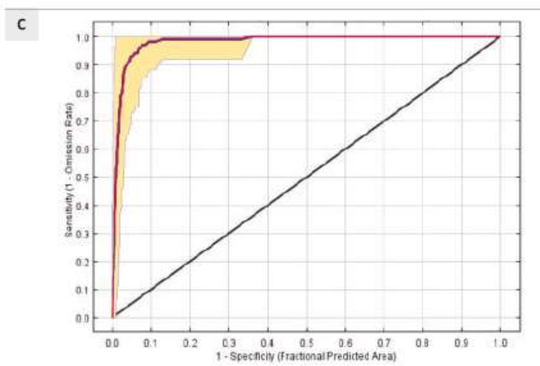




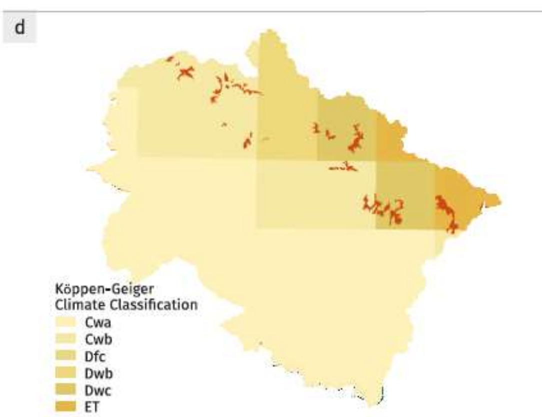


Plate 5.13
Eco-distribution of *Betula utilis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Forest Types	14/C1a, 14/C1b
Soil Texture	Rock outcrops
Climatic Status	Sub-alpine
KGCC	Cwb
Maximum Species Occurrence	Uttrakashi, Pithoragarh

Accuracy Measures

No. of Sample Points	73
AUC	0.981±0.029
Kappa	0.701
TSS	0.786
NMI	0.409
Environmental Variables	Bio 19, Soil, Bio 14

Area Occurrence

Estimated Area (km²)	305.16
VDF (km²)	11.75
MDF (km²)	241.14
OF (km²)	52.27
Total Forest Cover (%)	1.26
Total Geographical Area (%)	0.57

Populus ciliata

Geographical Attributes

Altitude Range(m)	879–3,234
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttrakashi, Tehri

Accuracy Measures

No. of Sample Points	73
AUC	0.919±0.162
Kappa	0.414
TSS	0.745
NMI	0.452
Environmental Variables	Soil, Vap

Area Occurrence

Estimated Area (km²)	237.27
VDF (km²)	37.36
MDF (km²)	156.61
OF (km²)	43.3
Total Forest Cover (%)	0.98
Total Geographical Area (%)	0.44

a

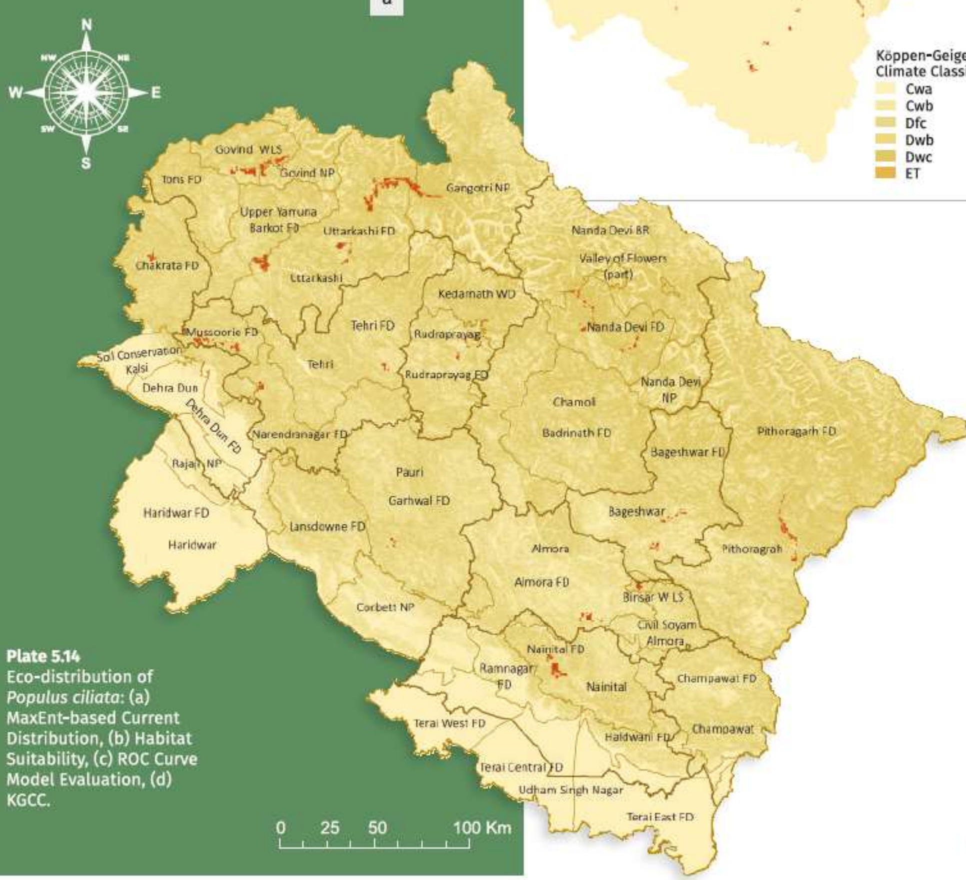
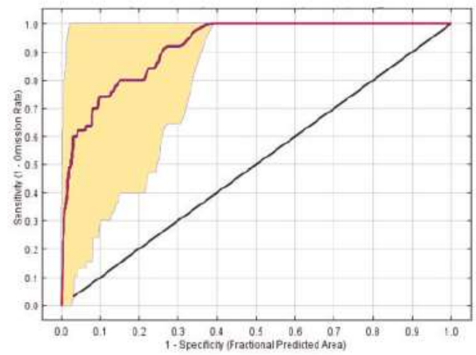


Plate 5.14
Eco-distribution of *Populus ciliata*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

b

c



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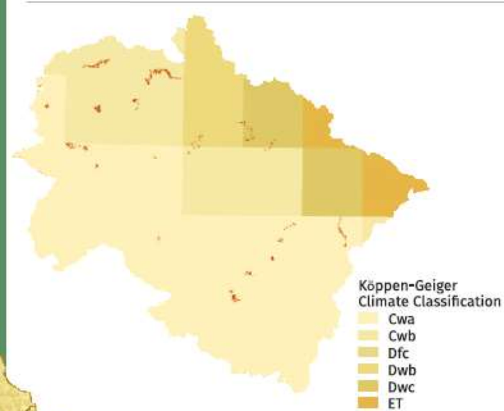

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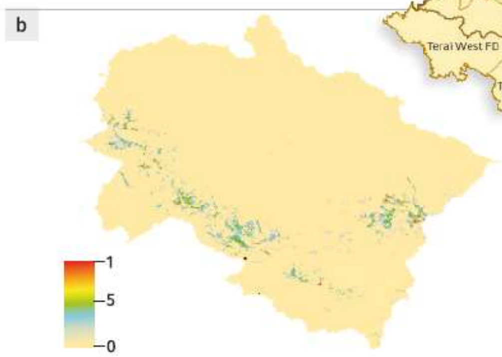
Terminalia Chebula
District Boundary
Boundary of Forest Division/ Protected Area

Terminalia chebula

a

b



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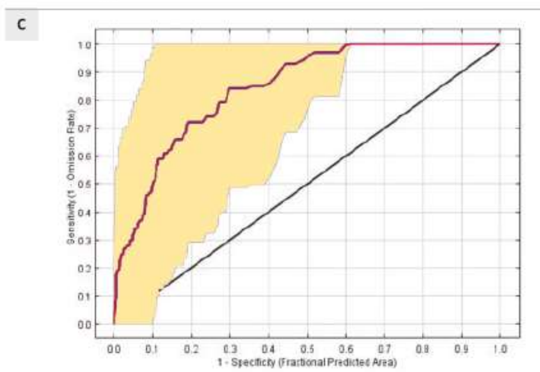

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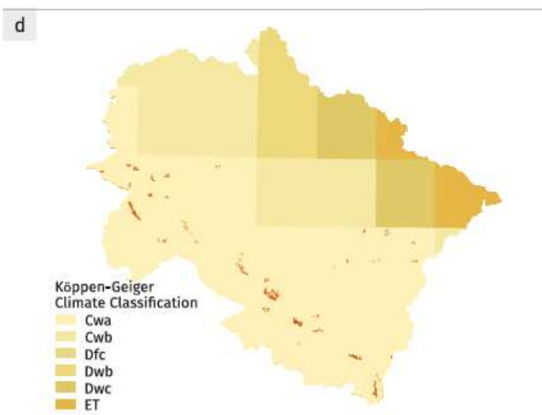

Plate 5.15
Eco-distribution of *Terminalia chebula*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range(m)	222-1,602
Forest Types	9/C1b, 3C/C2a, 3C/C2c, 5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Nainital, Haridwar

Accuracy Measures

No. of Sample Points	73
AUC	0.843±0.153
Kappa	0.260
TSS	0.832
NMI	0.550
Environmental Variables	Soil, Bio 1, Bio 2

Area Occurrence

Estimated Area (km^2)	262.89
VDF (km^2)	64.96
MDF (km^2)	145.92
OF (km^2)	52.01
Total Forest Cover (%)	1.08
Total Geographical Area (%)	0.49

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Hymenodictyon orixense

Geographical Attributes

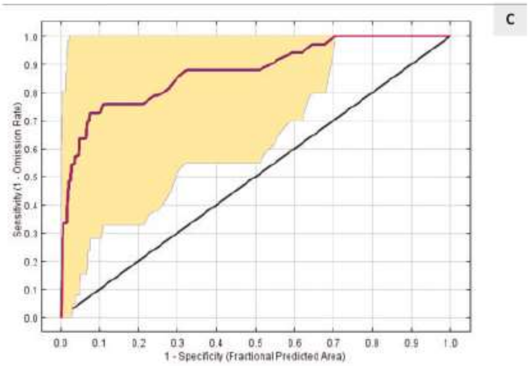
Altitude Range (m)	223-1,207
Forest Types	5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Nainital, Pithoragarh

Accuracy Measures

No. of Sample Points	59
AUC	0.875±0.019
Kappa	0.429
TSS	0.901
NMI	0.387
Environmental Variables	Soil, Bio 1

Area Occurrence

Estimated Area (km²)	249.83
VDF (km²)	67.38
MDF (km²)	138.39
OF (km²)	40.37
Total Forest Cover (%)	1.03
Total Geographical Area (%)	0.47



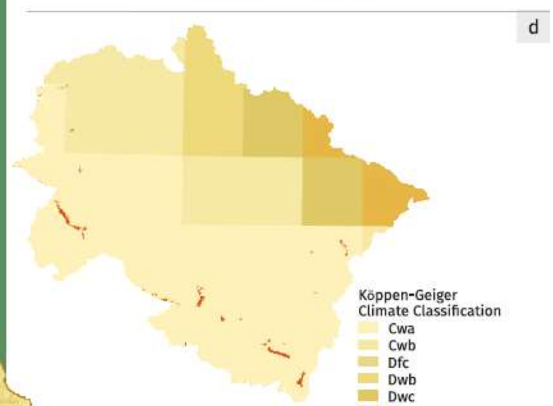


Plate 5.16
Eco-distribution of *Hymenodictyon orixense*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Prunus cerasoides
District Boundary
Boundary of Forest Division/ Protected Area

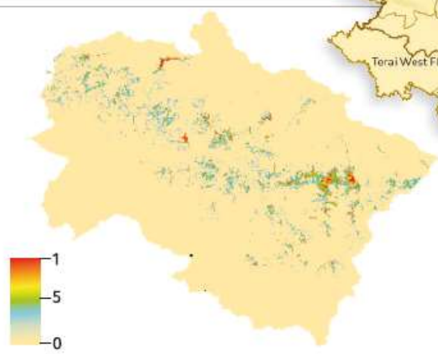
Prunus cerasoides

a

N W E S NW NE SW SE

0 25 50 100 Km

b



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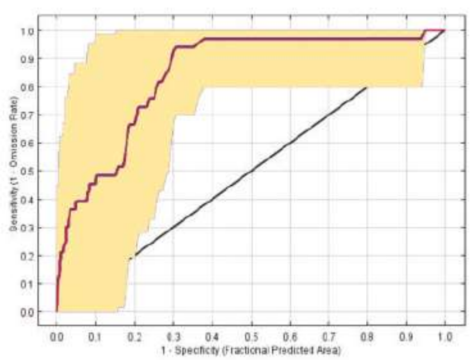

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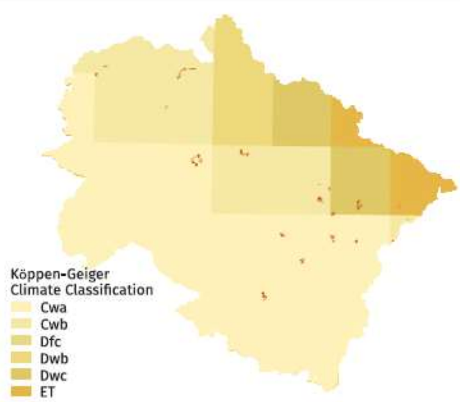

Plate 5.17
Eco-distribution of *Prunus cerasoides*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range(m)	1,320–2,954
Forest Types	12/C1a, 12/C1b, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Pithoragarh, Uttarkashi

Accuracy Measures

No. of Sample Points	46
AUC	0.844±0.177
Kappa	0.363
TSS	0.814
NMI	-0.003
Environmental Variables	Soil, Bio 1

Area Occurrence

Estimated Area (km^2)	185.99
VDF (km^2)	26.77
MDF (km^2)	110.35
OF (km^2)	48.87
Total Forest Cover (%)	0.77
Total Geographical Area (%)	0.35

Cinnamomum tamala

Geographical Attributes

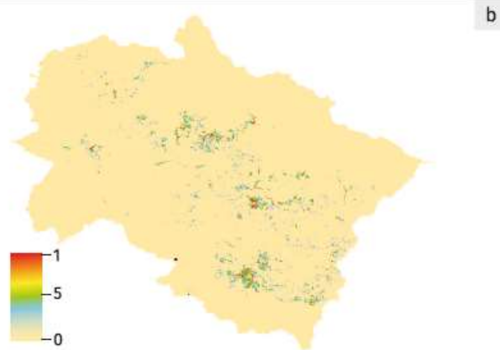
Altitude Range(m)	886–2,619
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Nainital, Bageshwar

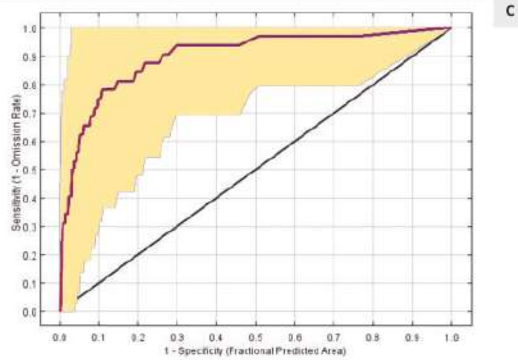
Accuracy Measures

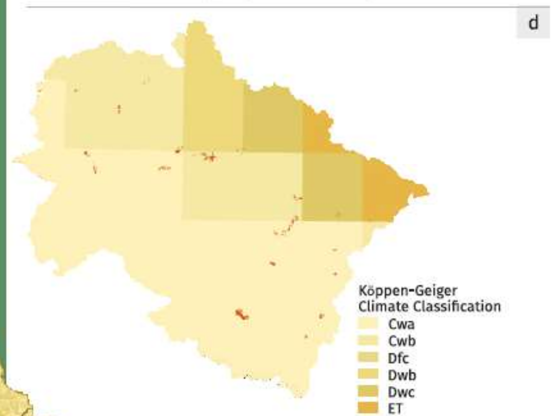
No. of Sample Points	44
AUC	0.902±0.162
Kappa	0.285
TSS	0.703
NMI	0.463
Environmental Variables	Bio 4, Soil

Area Occurrence

Estimated Area (km^2)	158.62
VDF (km^2)	43.25
MDF (km^2)	81.79
OF (km^2)	33.57
Total Forest Cover (%)	0.65
Total Geographical Area (%)	0.30







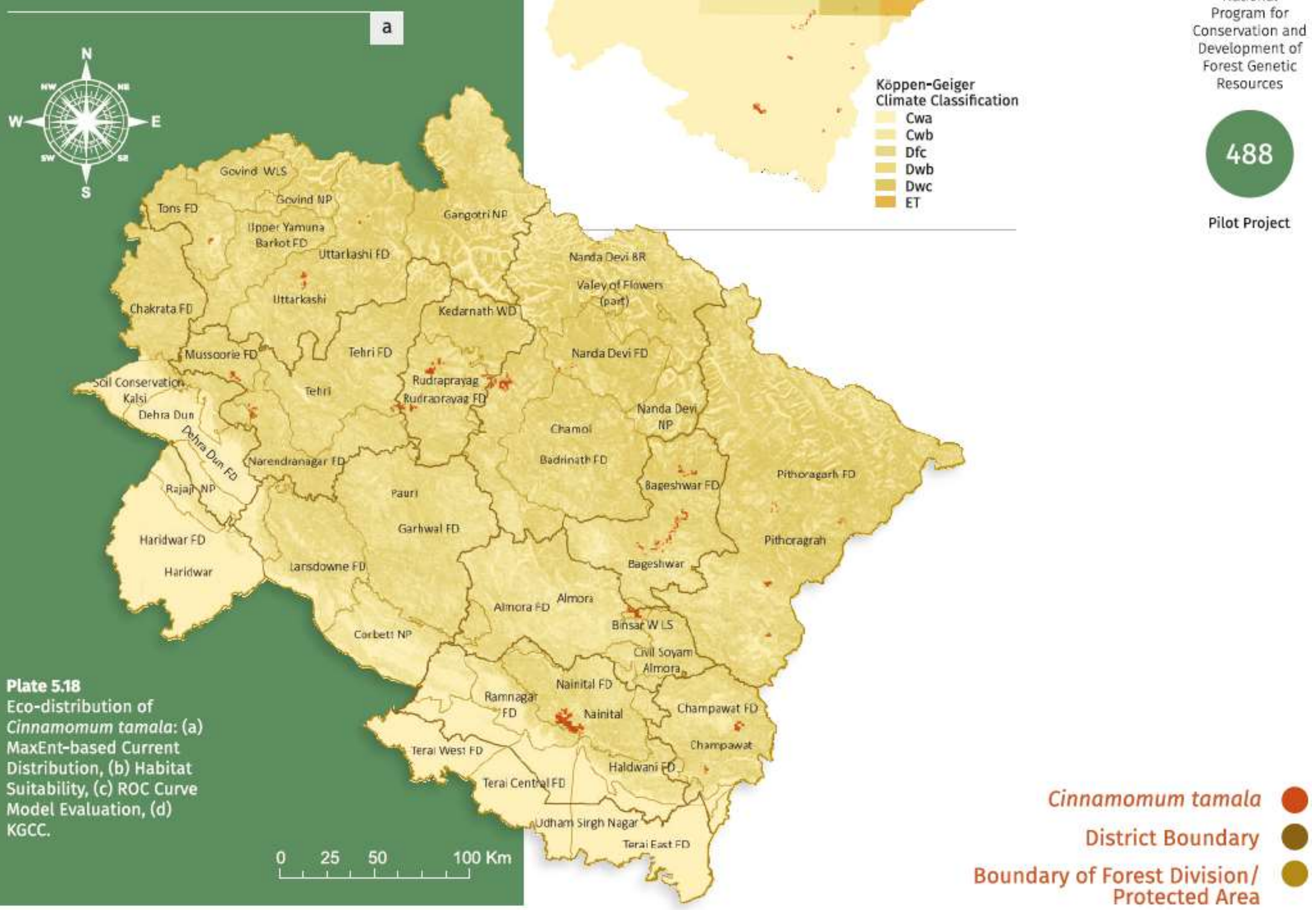


Plate 5.18
Eco-distribution of *Cinnamomum tamala*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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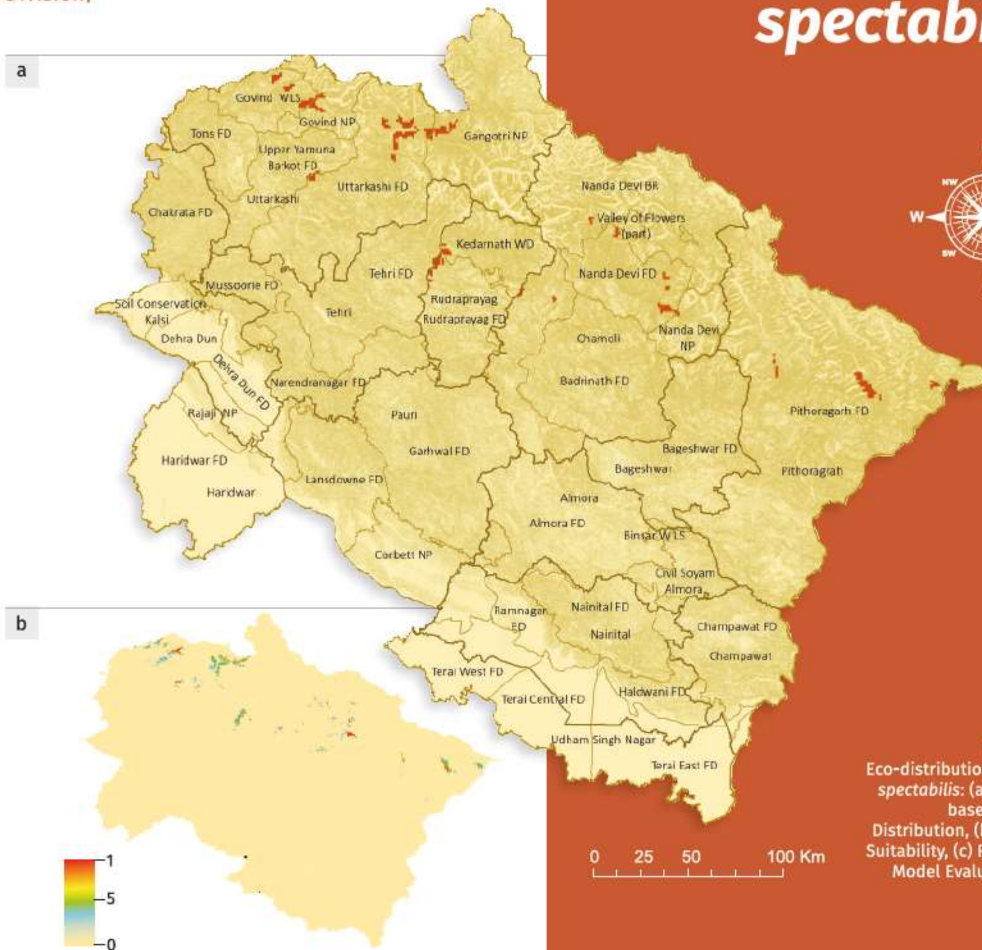
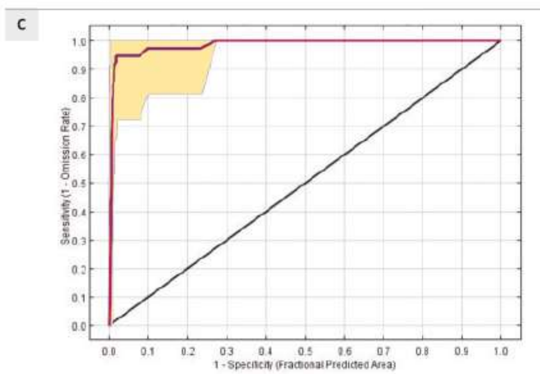
Abies spectabilis
District Boundary
Boundary of Forest Division/ Protected Area

Abies spectabilis





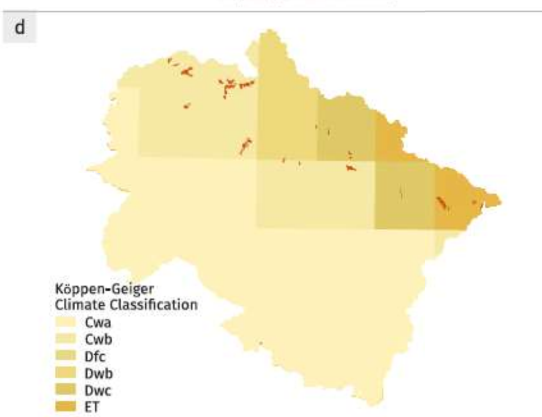


Plate 5.19
Eco-distribution of *Abies spectabilis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range (m)	2,712–3, 684
Forest Types	12/C2b, 14C1a, 14C1b
Soil Texture	Rock outcrops
Climatic Status	Sub-alpine
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Rudraprayag

Accuracy Measures

No. of Sample Points	40
AUC	0.986±0.041
Kappa	0.719
TSS	0.71
NMI	0.374
Environmental Variables	Bio 14, Soil, Bio 8

Area Occurrence

Estimated Area (km²)	147.85
VDF (km²)	8.54
MDF (km²)	113.37
OF (km²)	25.94
Total Forest Cover (%)	0.61
Total Geographical Area (%)	0.28

Alnus nepalensis

Geographical Attributes

Altitude Range (m)	1,227-3,044
Forest Types	12/C1a, 12/c1b, 12/C1e, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Chamoli, Uttrakashi

Accuracy Measures

No. of Sample Points	40
AUC	0.913±0.116
Kappa	0.364
TSS	0.75
NMI	-0.364
Environmental Variables	Bio 15, Bio 6, Bio 5

Area Occurrence

Estimated Area (km²)	143.65
VDF (km²)	34.79
MDF (km²)	75.43
OF (km²)	33.43
Total Forest Cover (%)	0.59
Total Geographical Area (%)	0.27

a

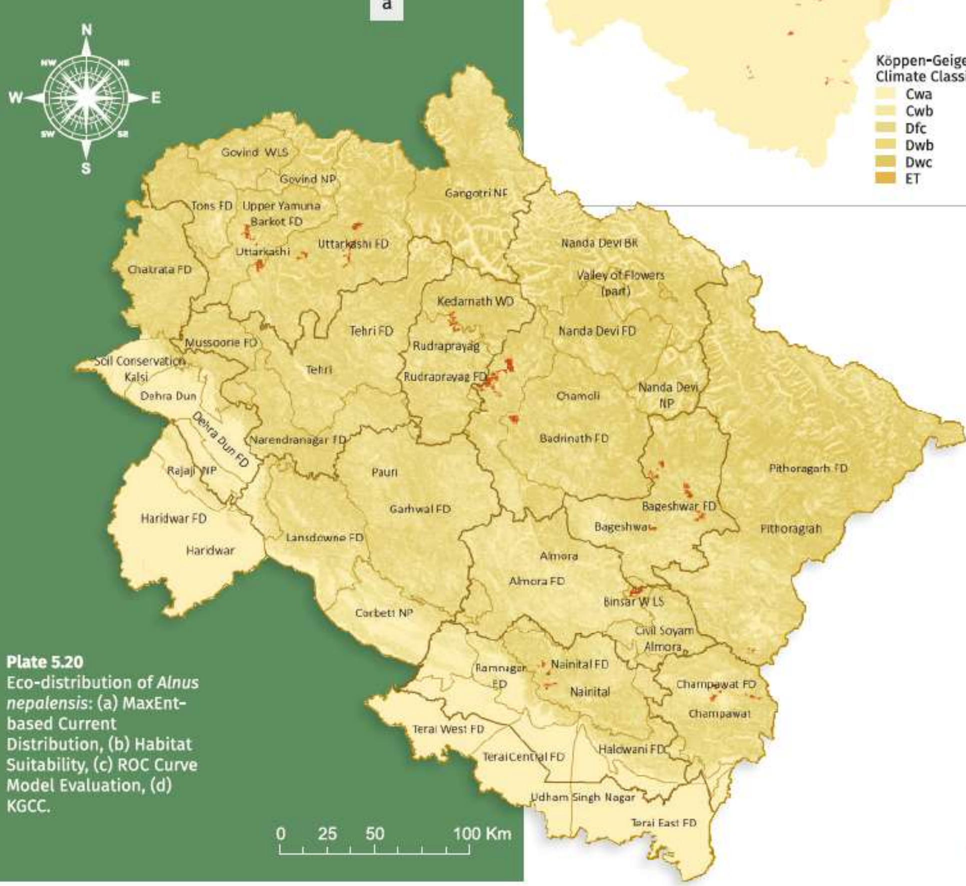
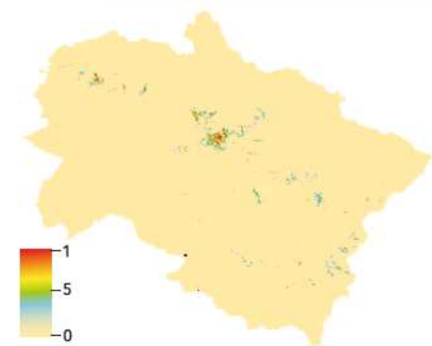
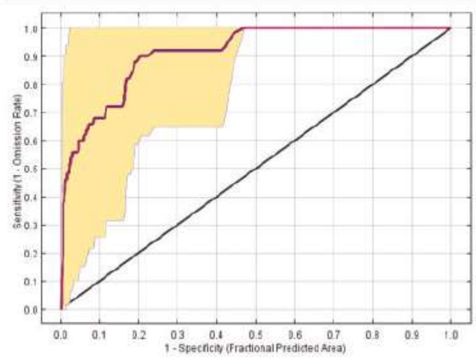


Plate 5.20
Eco-distribution of *Alnus nepalensis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

b



c



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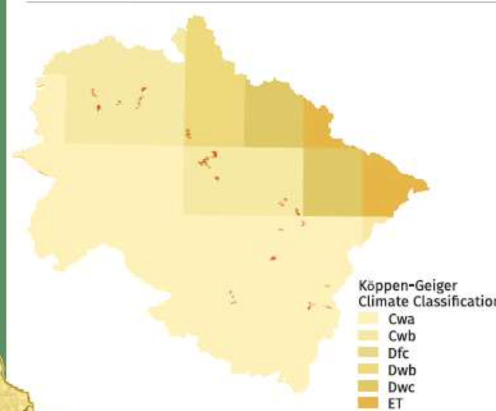

Conservation of Forest Genetic Resources

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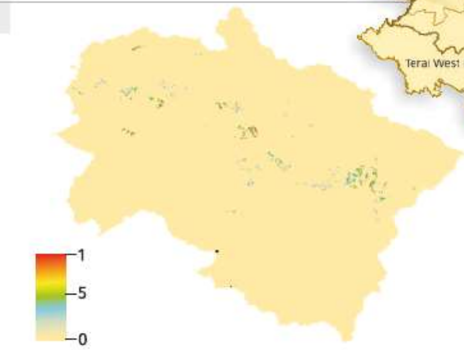
Pilot Project

Alnus nepalensis
District Boundary
Boundary of Forest Division/ Protected Area

Buxus wallichiana

a

b



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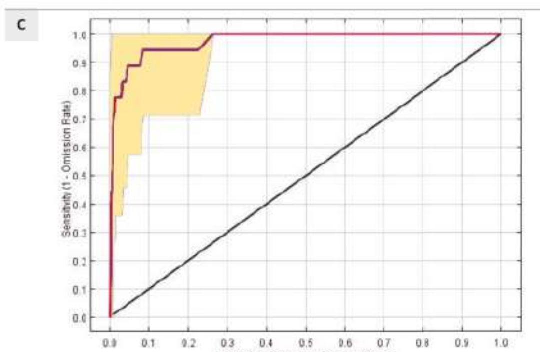

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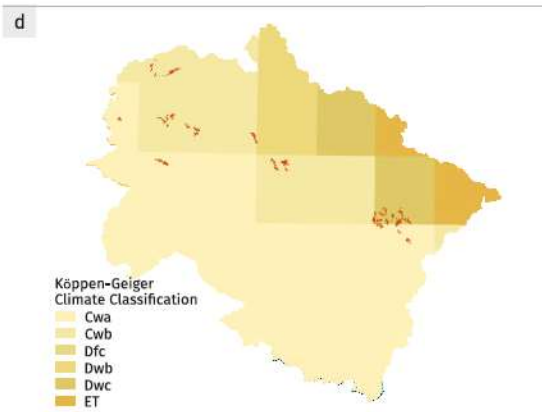


Plate 5.21
Eco-distribution of *Buxus wallichiana*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range (m)	2,141–2,646
Forest Types	12/C1a, 12C1/b, 12/C1e, 12/C2c
Soil Texture	Loamy skeletal
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Pithoragarh

Accuracy Measures

AUC	0.974±0.058
Kappa	0.587
TSS	0.832
NMI	0.338
Environmental Variables	Soil, Bio 8

Area Occurrence

Estimated Area (km^2)	187.57
VDF (km^2)	62.81
MDF (km^2)	95.84
OF (km^2)	28.92
Total Forest Cover (%)	0.77
Total Geographical Area (%)	0.35

Semecarpus anacardium

Geographical Attributes

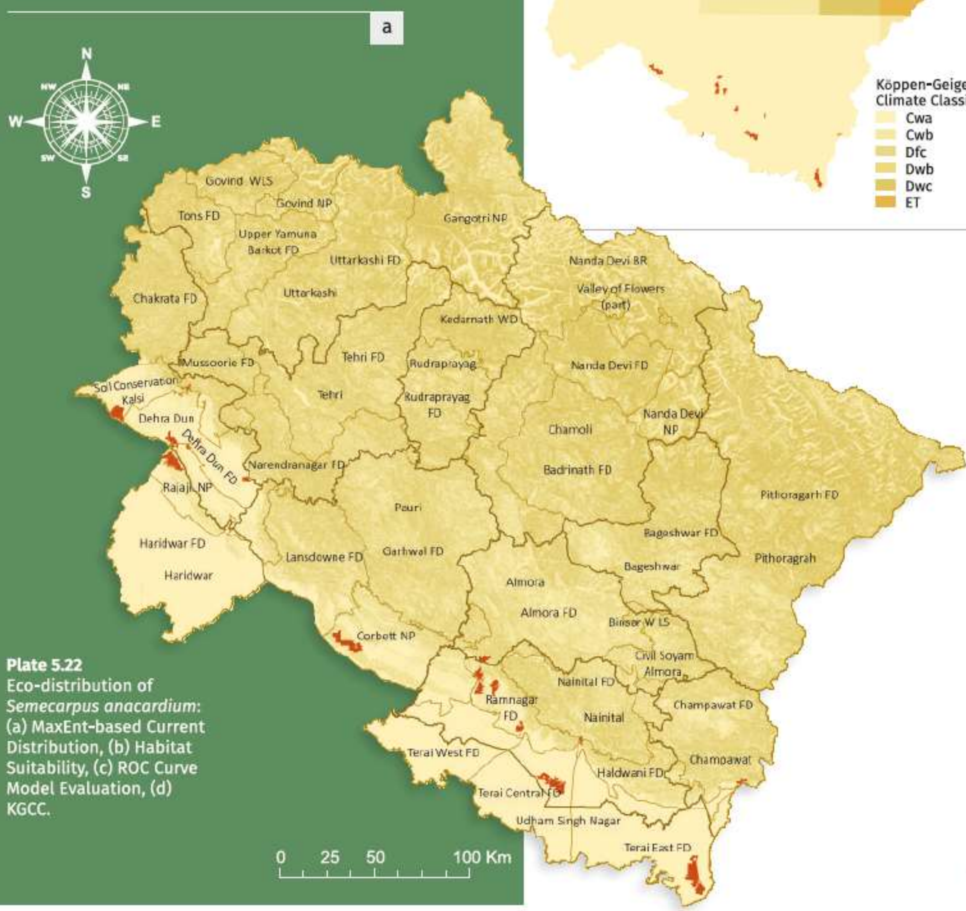
Altitude Range (m)	210–1,447
Forest Types	3C/C2a, 3C/C3a, 5B/C1b, 5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Nainital, Udham singh nagar

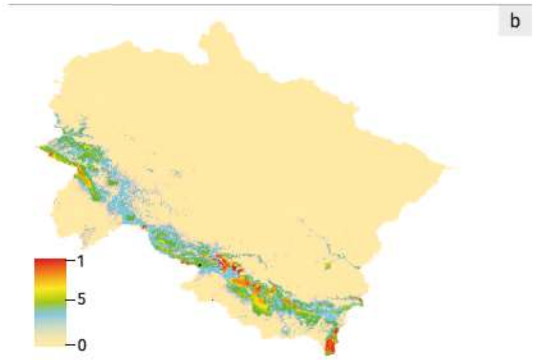
Accuracy Measures

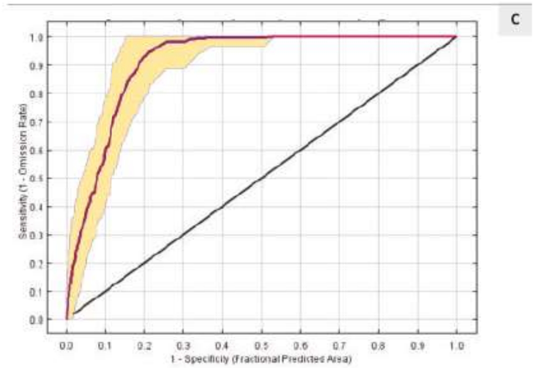
No. of Sample Points	38
AUC	0.910±0.035
Kappa	0.200
TSS	0.818
NMI	–0.003
Environmental Variables	Soil, Alt

Area Occurrence

Estimated Area (km²)	227.91
VDF (km²)	94.19
MDF (km²)	117.85
OF (km²)	15.87
Total Forest Cover (%)	0.94
Total Geographical Area (%)	0.43







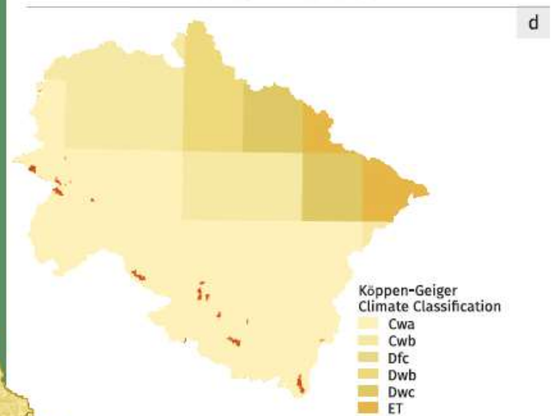


Plate 5.22
Eco-distribution of *Semecarpus anacardium*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Pilot Project

Semecarpus anacardium
District Boundary
Boundary of Forest Division/ Protected Area

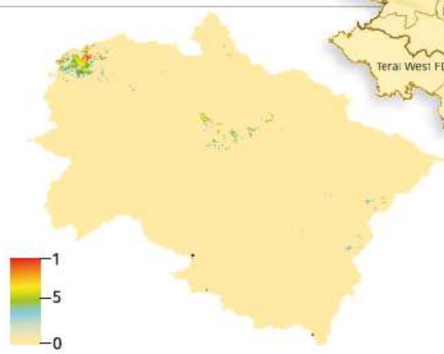
Hovenia dulcis
District Boundary
Boundary of Forest Division/ Protected Area

Hovenia dulcis

a

Plate 5.23
Eco-distribution of *Hovenia dulcis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

b



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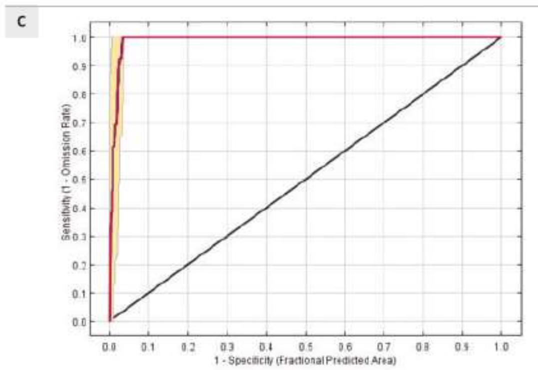

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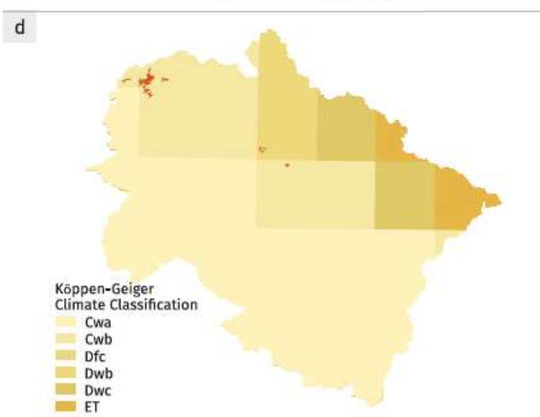

Conservation of Forest Genetic Resources

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Uttarakhand State

Geographical Attributes

Altitude Range (m)	1,218–2,174
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy skeletal
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi

Accuracy Measures

No. of Sample Points	38
AUC	0.989±0.010
Kappa	0.384
TSS	0.884
NMI	–0.002
Environmental Variables	Soil, LULC

Area Occurrence

Estimated Area (km^2)	77.10
VDF (km^2)	22.67
MDF (km^2)	34.76
OF (km^2)	19.67
Total Forest Cover (%)	0.32
Total Geographical Area (%)	0.14

5.7.1.3

Class-III (10 – <35 Geo-coordinates)

This class holds a total of 14 species with an overall altitude ranging from 207 m to 3,423 m. According to the FTM, Class-III species were distributed in 12/C1e, 9/C1b, 12/C1a, 12/C2 a, 12/C1b, 3C/C2a, 12C1f, 5B/C2, 12/2S1, 14/C1b, 5B/C1a and 5B/C1b forest sub-types (Plate 5.24 to 5.37). The values of AUC varied from 0.834±0.058 (*P. mollissima*) to 0.999±0.000 (*Tsuga dumosa*) for prediction mapping, with classification accuracy measures, *K* from 0.052 (*P. mollissima*) to 0.941 (*T. dumosa*) and TSS from 0.401 (*Phanera retusa*) to 1.00 (*T. dumosa*). While using ground-based points, maximum of 90.91 per cent and 90.00 per cent falls in the prediction threshold of *U. wallichiana* and *B. cochinchinensis*, respectively have fallen. Whereas, minimum (70.00 per cent) ground-based points were recorded in case of *C. jacquemontii*. The environmental variables, namely, Soil, Bio 1, Bio 4, Bio 5, Bio 6, Bio 10, Bio 15, Bio 16, wind, LULC, altitude and aspect showed highest contribution in predicting the distribution of 14 species (Table 5.5; Plate 5.24 to 5.37).

The ecogeographic distribution maps revealed an actual estimated area of 1,845.44 km^2 for 14 species, which was 3.45 per cent of the total geographical area, and 7.59 per cent of the total forest cover and 19.34 per cent of the PAs (Table 5.5). Interestingly, maximum and minimum occurrence under PAs were observed for *U. wallichiana* (99.96 per cent) and *F. neriifolia* (5.77 per cent), respectively. In addition, the values of area under VDF, MDF and OF estimated were 418.21 km^2, 847.44 km^2 and 380.38 km^2, respectively. Notably, maximum (MDF=113.22 km^2), and minimum (VDF=1.71 km^2) occurrence areas were recorded for *Ficus neriifolia* and *T. dumosa*, respectively, especially in Bageshwar, Uttarkashi and Pithoragarh districts. The ecogeographic distribution map showed maximum occurrence of these species in Cwb (C=warm temperate, w=winter dry, and b=warm summer) subtropical highland oceanic climate of upper zonation of middle Himalayas and Cwa (C=warm temperate, w=winter dry, and a=hot summer) humid subtropical climate in lower stretches of middle Himalayas. Overall, *T. dumosa* dominated in this class with minimum values of accuracy estimators, and *F. neriifolia* for maximum estimated area, whereas Uttarkashi district for occurrence record to cover FTM (Fig. 5.4).

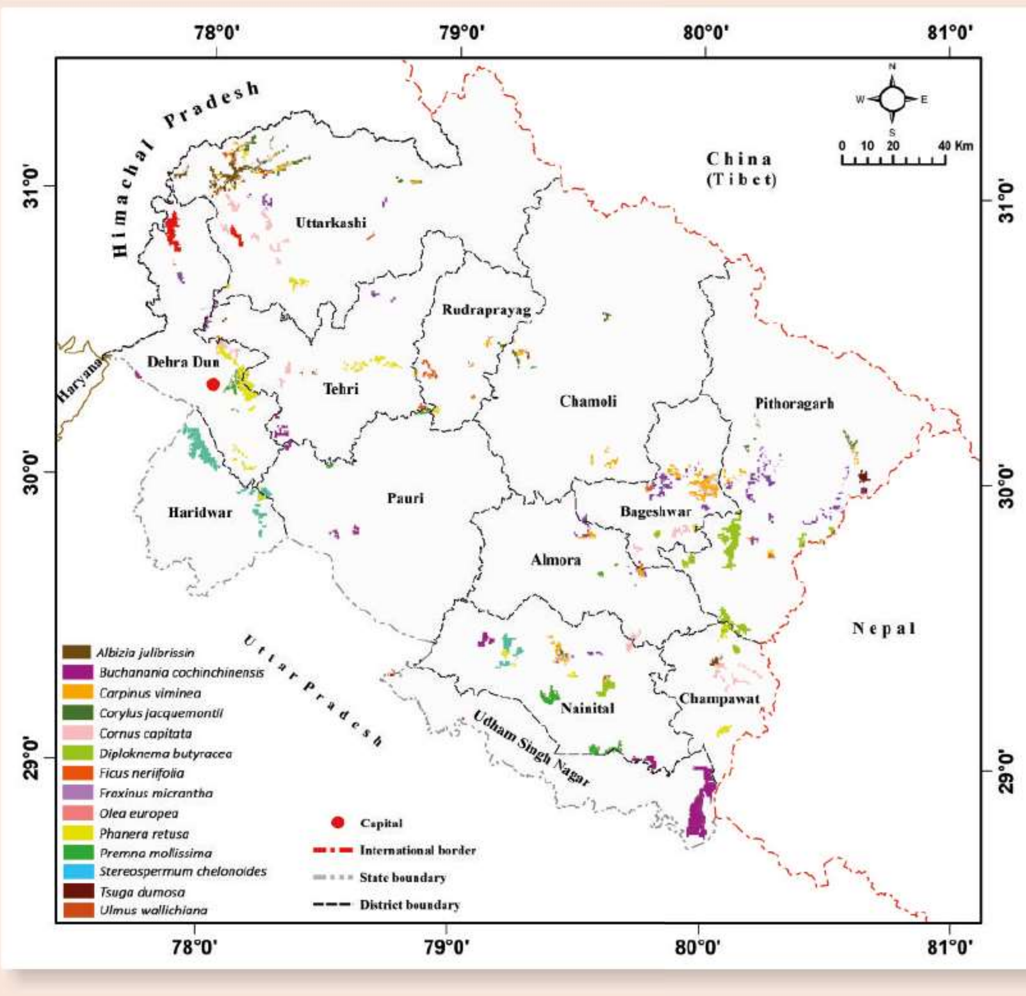
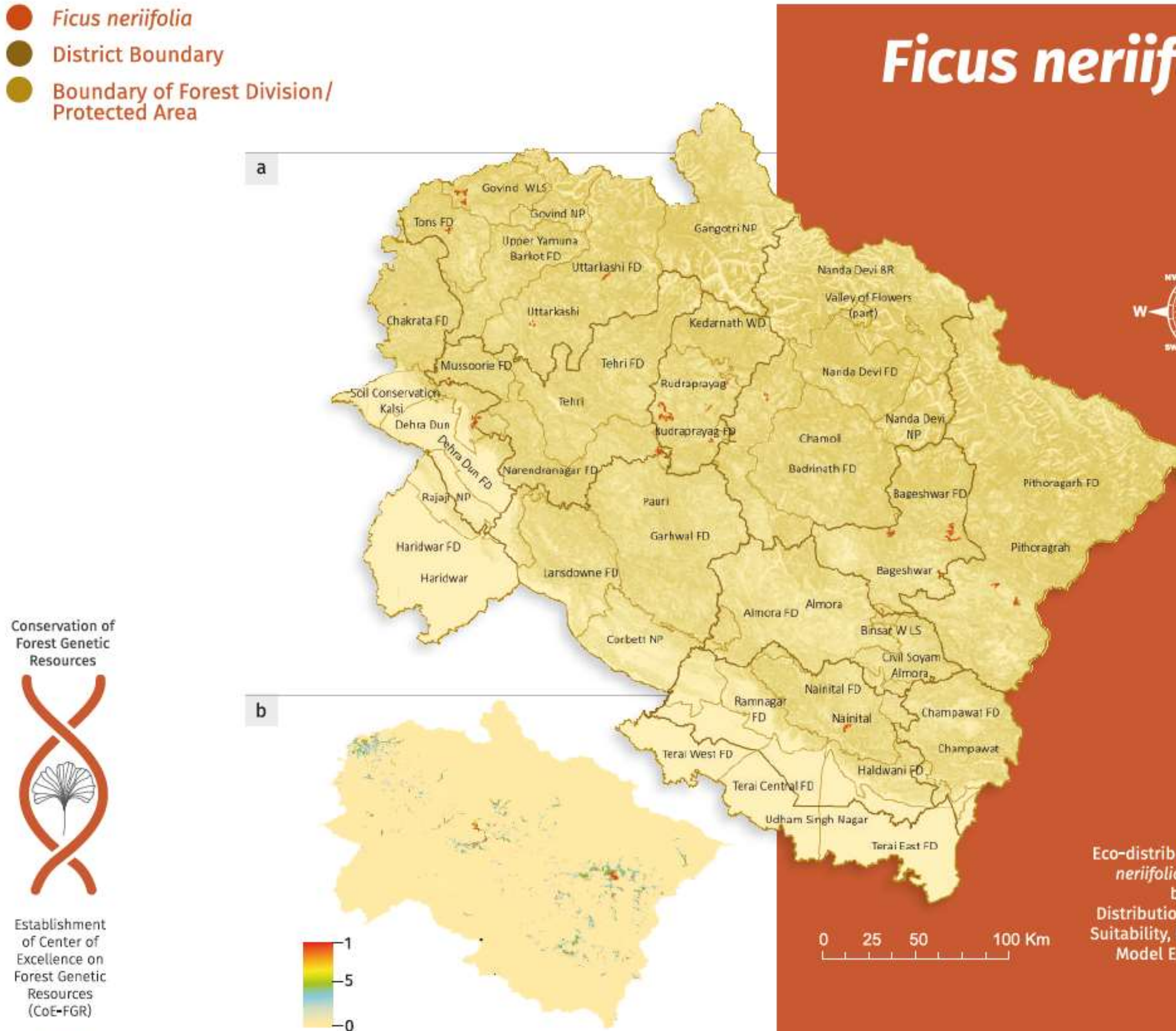
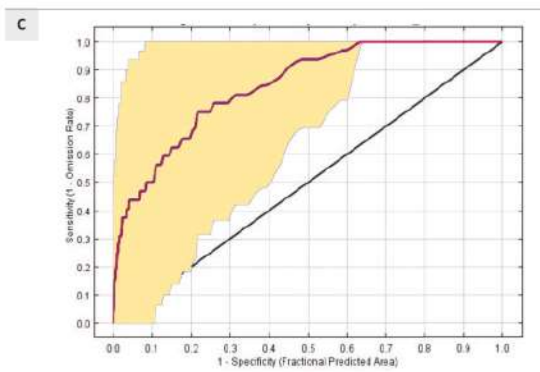


Fig. 5.4 Mapping of Ecogeographic Distribution of Fourteen Species Having Geo-coordinates Ranged from >10 to <35

Ficus neriifolia





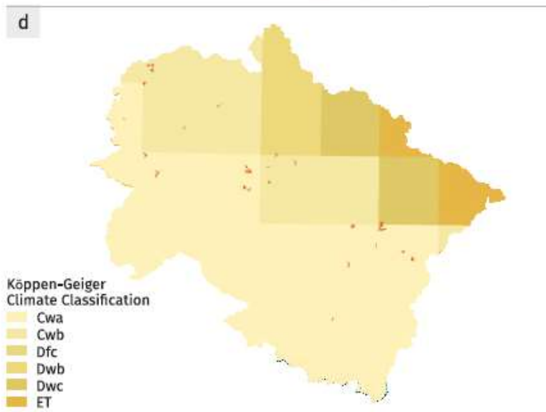


Plate 5.24
Eco-distribution of *Ficus neriifolia*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range (m)	662–2,371
Forest Types	12/C1a, 12/C1b, 9/C1b, 5B/C2
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Bageshwar, Uttrakashi

Accuracy Measures

No. of Sample Points	34
AUC	0.845±0.175
Kappa	0.466
TSS	0.887
NMI	−0.003
Environmental Variables	Soil, Vap, Bio 4

Area Occurrence

Estimated Area (km^2)	218.25
VDF (km^2)	46.85
MDF (km^2)	113.22
OF (km^2)	58.18
Total Forest Cover (%)	0.90
Total Geographical Area (%)	0.41

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Carpinus viminea

Geographical Attributes

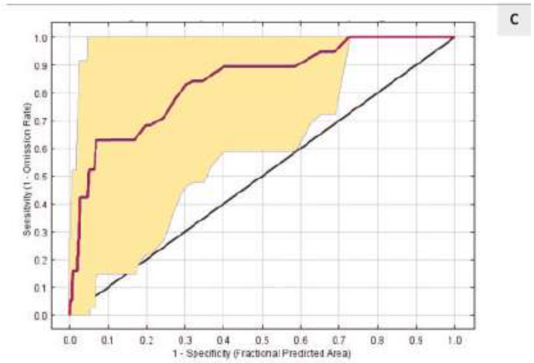
Altitude Range (m)	1,646–2,471
Forest Types	12/C1a, 12/C1b, 12/C1e
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Bageshwar, Uttarkashi

Accuracy Measures

No. of Sample Points	32
AUC	0.838±0.206
Kappa	0.207
TSS	0.902
NMI	–0.002
Environmental Variables	Soil, Bio 1, Bio 4

Area Occurrence

Estimated Area (km²)	174.26
VDF (km²)	50.11
MDF (km²)	90.24
OF (km²)	33.9
Total Forest Cover (%)	0.72
Total Geographical Area (%)	0.33



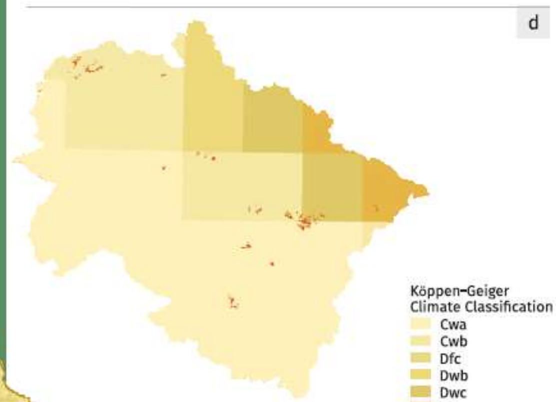


Plate 5.25
Eco-distribution of *Carpinus viminea*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Carpinus viminea
District Boundary
Boundary of Forest Division/ Protected Area

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- *Fraxinus micrantha*
- District Boundary
- Boundary of Forest Division/ Protected Area

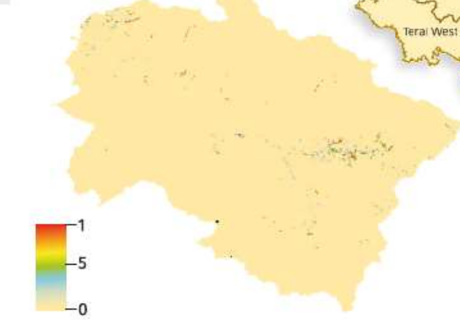
Fraxinus micrantha

a

N W E S NW NE SW SE

0 25 50 100 Km

b



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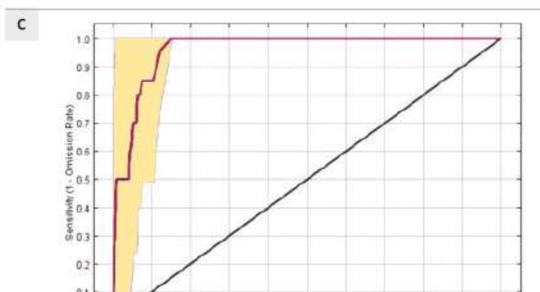

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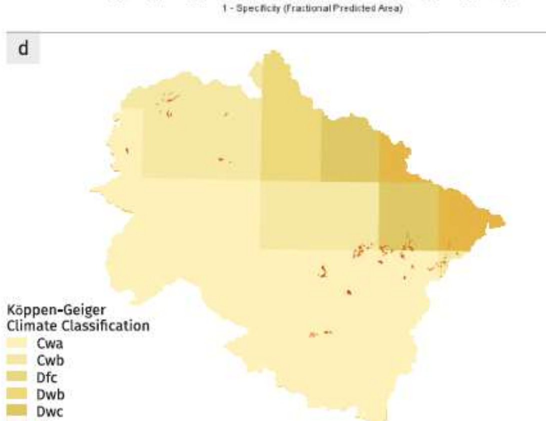

Plate 5.26
Eco-distribution of *Fraxinus micrantha*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range(m)	1,246-2,622
Forest Types	12/C1a, 12/C1b, 12/C1e, 12/C1f
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Pithoragarh, Bageshwar

Accuracy Measures

No. of Sample Points	31
AUC	0.960±0.042
Kappa	0.658
TSS	0.933
NMI	0.337
Environmental Variables	Bio 14, Soil, Alt

Area Occurrence

Estimated Area (km²)	198.47
VDF (km²)	67.95
MDF (km²)	103.26
OF (km²)	27.26
Total Forest Cover (%)	0.82
Total Geographical Area (%)	0.37

Cornus capitata

Geographical Attributes

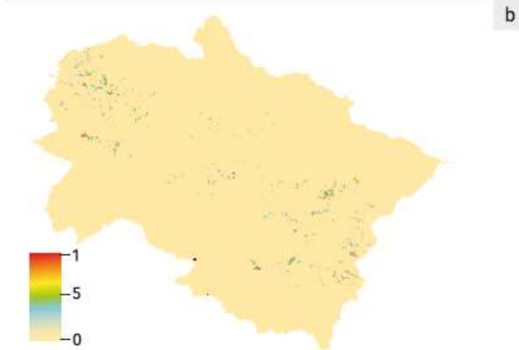
Altitude Range (m)	1,636–2,118
Forest Types	12/C1a, 12/C1b, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Uttarakashi, Champawat

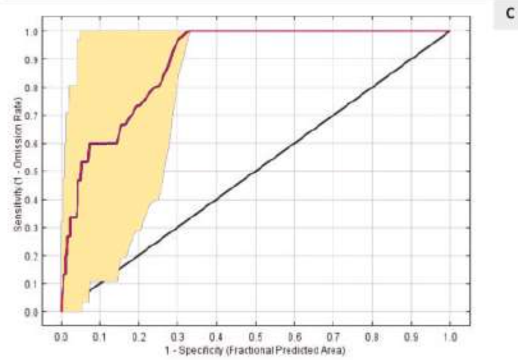
Accuracy Measures

No. of Sample Points	30
AUC	0.891±0.105
Kappa	0.425
TSS	0.863
NMI	0.347
Environmental Variables	Soil, Bio 10, LULC

Area Occurrence

Estimated Area (km²)	146.28
VDF (km²)	56.17
MDF (km²)	56.07
OF (km²)	34.04
Total Forest Cover (%)	0.60
Total Geographical Area (%)	0.27





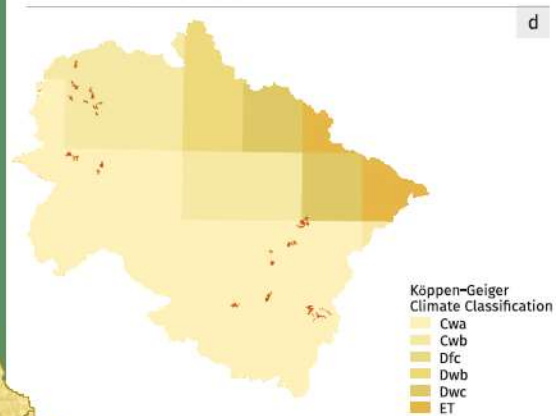


Plate 5.27
Eco-distribution of *Cornus capitata*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Cornus capitata
District Boundary
Boundary of Forest Division/ Protected Area

Conservation of Forest Genetic Resources

National Program for Conservation and Development of Forest Genetic Resources

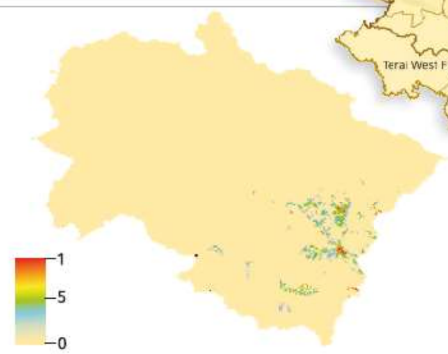
Pilot Project

Diploknema butyracea

- *Diploknema butyracea*
- District Boundary
- Boundary of Forest Division/ Protected Area

a

b



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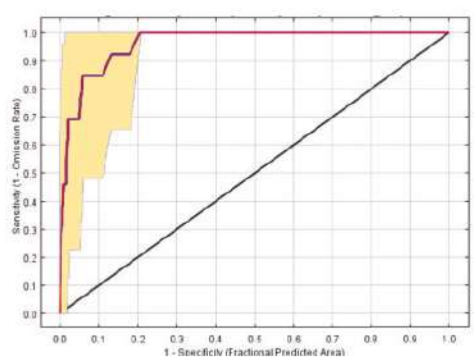

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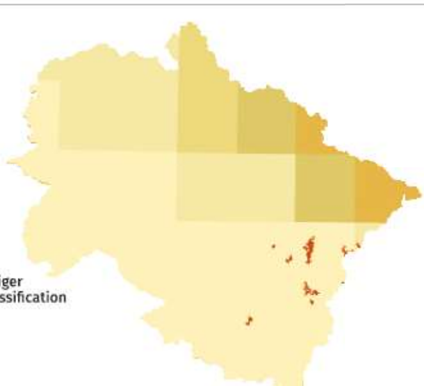

Plate 5.28
Eco-distribution of *Diplokneme butyracea*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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Geographical Attributes

Altitude Range (m)	509-1,526
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Pithoragarh, Nainital

Accuracy Measures

No. of Sample Points	30
AUC	0.961±0.059
Kappa	0.306
TSS	0.764
NMI	0.436
Environmental Variables	Soil

Area Occurrence

Estimated Area (km²)	200.10
VDF (km²)	-
MDF (km²)	-
OF (km²)	-
Total Forest Cover (%)	0.37
Total Geographical Area (%)	0.82

Corylus jacquemontii

Geographical Attributes

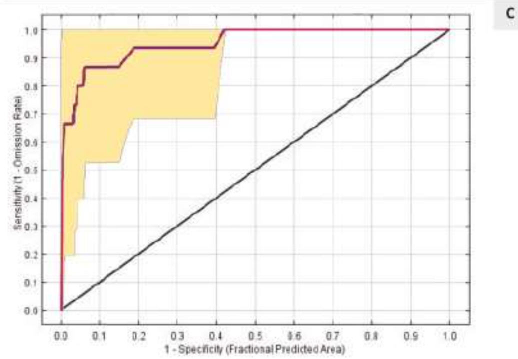
Altitude Range (m)	2,142-3,423
Forest Types	12/2S1, 14/C1b,
Soil Texture	Rock outcrops
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi, Pithoragarh

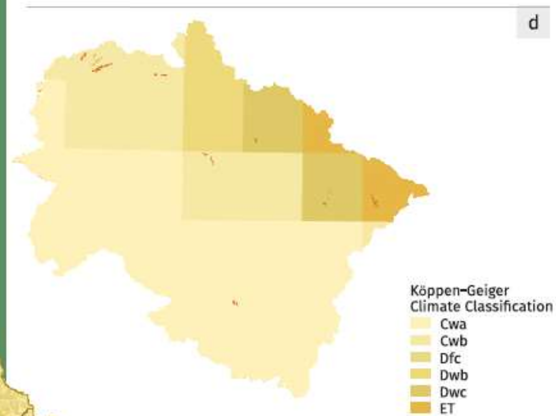
Accuracy Measures

No. of Sample Points	26
AUC	0.953±0.102
Kappa	0.532
TSS	0.885
NMI	-0.002
Environmental Variables	Soil, LULC

Area Occurrence

Estimated Area (km²)	76.83
VDF (km²)	9.67
MDF (km²)	54.33
OF (km²)	12.83
Total Forest Cover (%)	0.32
Total Geographical Area (%)	0.14





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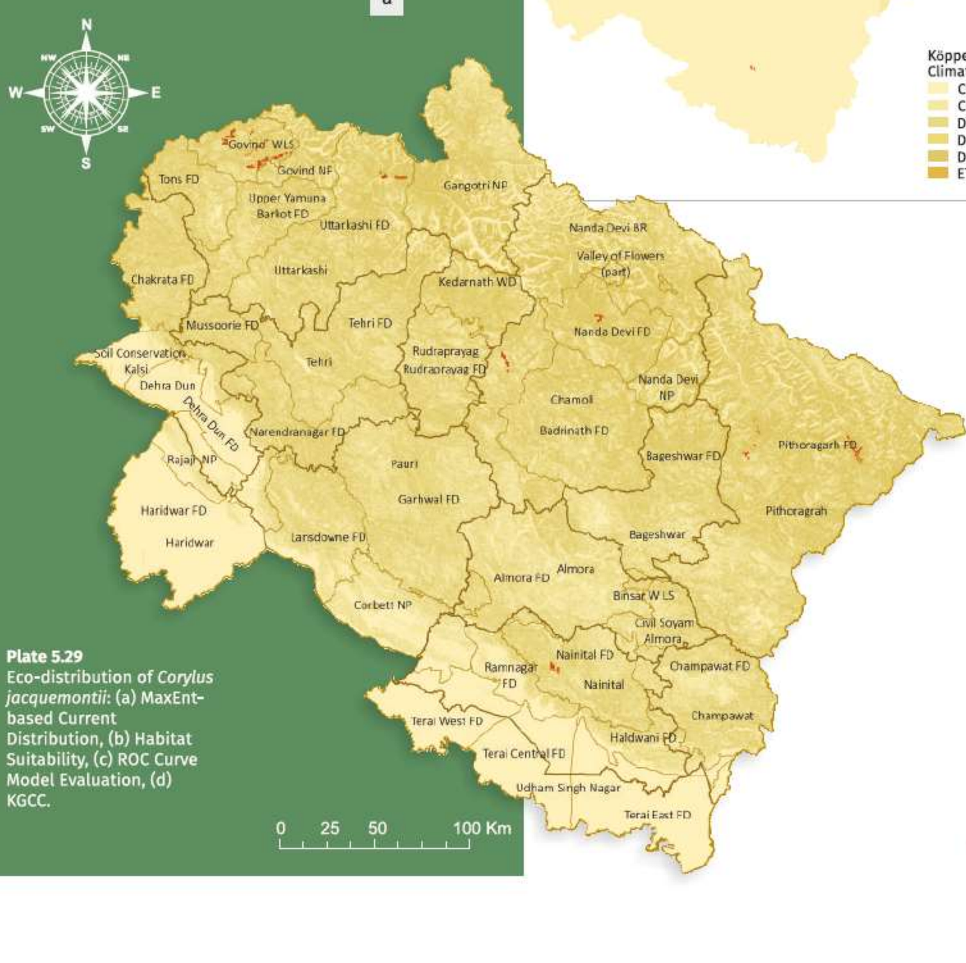


Plate 5.29
Eco-distribution of *Corylus jacquemontii*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

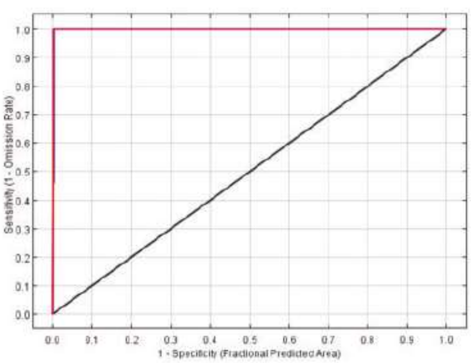
Tsuga dumosa
District Boundary
Boundary of Forest Division/ Protected Area

Tsuga dumosa

a

b

c



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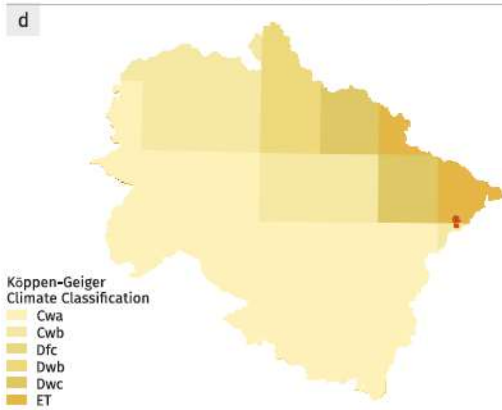

Plate 5.30
Eco-distribution of *Tsuga dumosa*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range (m)	2,630-3,367
Forest Types	12/C1d, 12/C2a
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	ET
Maximum Species Occurrence	Pithoragarh

Accuracy Measures

No. of Sample Points	24
AUC	0.999±0.000
Kappa	0.941
TSS	1
NMI	0.302
Environmental Variables	Soil, Bio 4

Area Occurrence

Estimated Area (km^2)	15.54
VDF (km^2)	4.59
MDF (km^2)	9.24
OF (km^2)	1.71
Total Forest Cover (%)	0.06
Total Geographical Area (%)	0.03

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Establishment of Center of Excellence on Forest Genetic Resources (CoE-FGR)

Uttarakhand State

Premna mollissima

Geographical Attributes

Altitude Range(m)	346–1,738
Forest Types	9/C1b, 3C/C2a, 5B/C1a, 5B/C2b
Soil Texture	Loamy skeletal
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Dehra Dun, Nainital

Accuracy Measures

No. of Sample Points	23
AUC	0.834±0.058
Kappa	0.052
TSS	0.883
NMI	−0.006
Environmental Variables	Soil, Bio 1

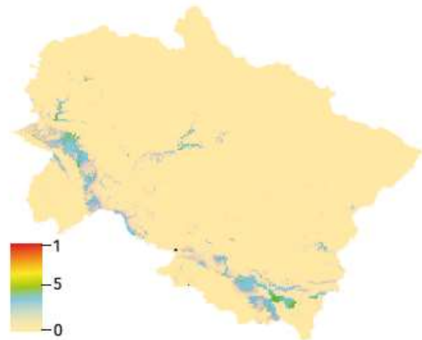
Area Occurrence

Estimated Area (km^2)	161.38
VDF (km^2)	45.38
MDF (km^2)	84.24
OF (km^2)	31.76
Total Forest Cover (%)	0.66
Total Geographical Area (%)	0.30

a

Plate 5.31
Eco-distribution of *Premna mollissima*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

b



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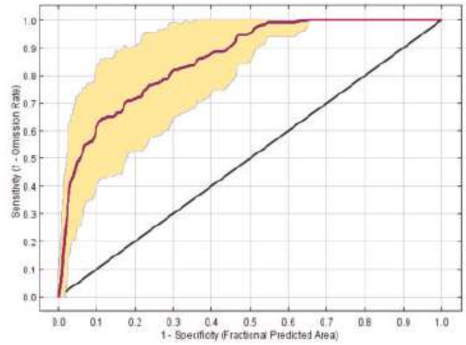

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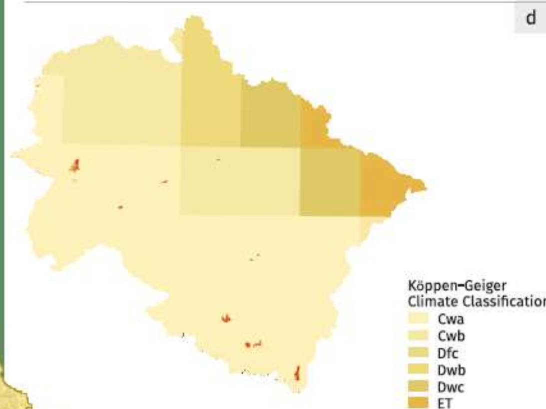

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National Program for Conservation and Development of Forest Genetic Resources

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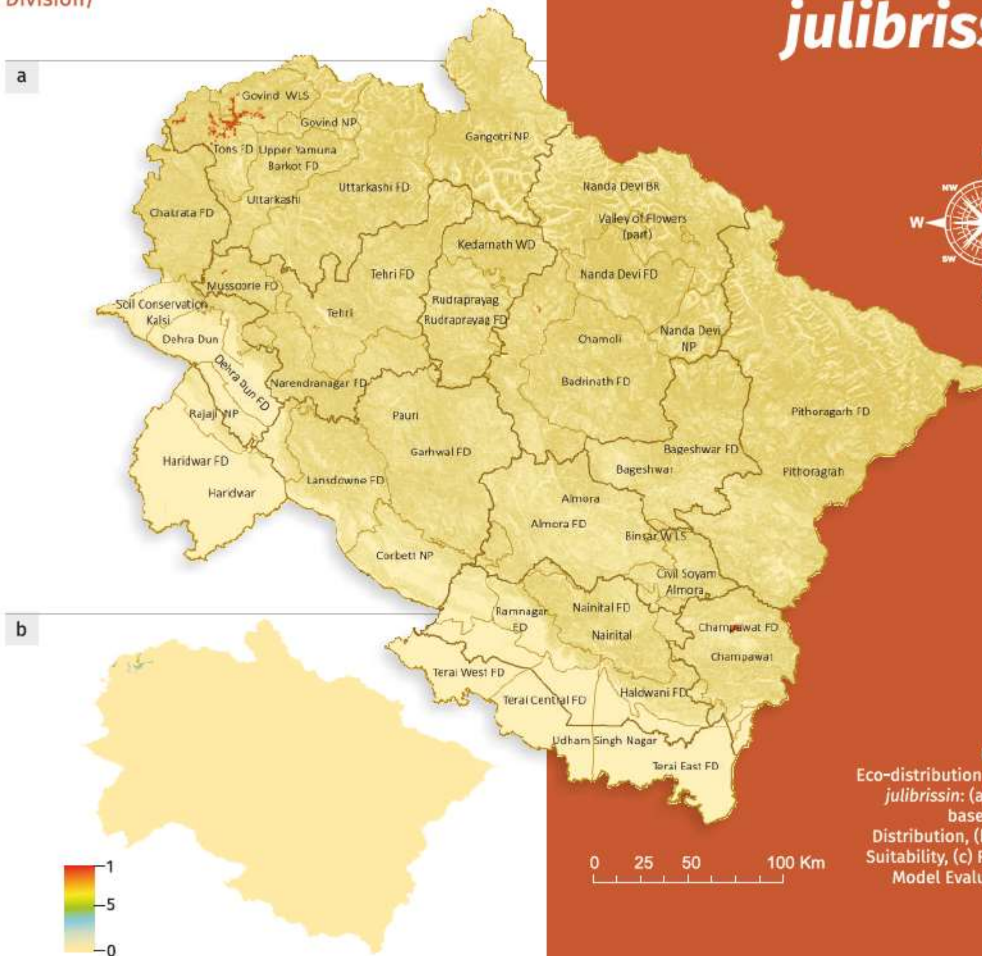
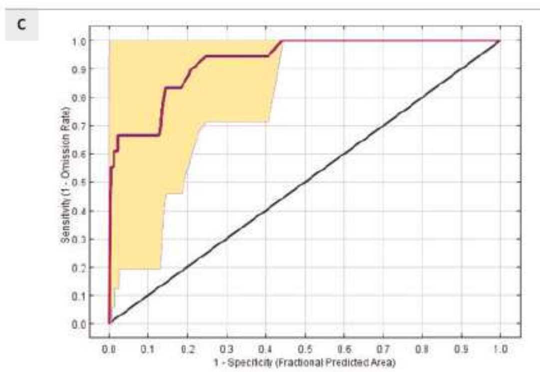
Pilot Project

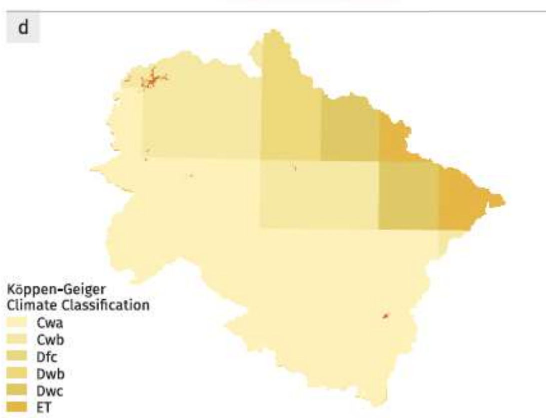
Premna mollissima
District Boundary
Boundary of Forest Division/ Protected Area

Albizia julibrissin

- *Albizia julibrissin*
- District Boundary
- Boundary of Forest Division/ Protected Area







Conservation of Forest Genetic Resources

Establishment of Center of Excellence on Forest Genetic Resources (CoE-FGR)

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Uttarakhand State

Plate 5.32
Eco-distribution of *Albizia julibrissin*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range(m)	1,131-2,295
Forest Types	12/C1a, 12/C1b, 9/C1b
Soil Texture	Loamy skeletal
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi

Accuracy Measures

No. of Sample Points	22
AUC	0.928±0.112
Kappa	0.580
TSS	0.997
NMI	0.002
Environmental Variables	Bio 15, Bio 5, Bio 6

Area Occurrence

Estimated Area (km^2)	78.98
VDF (km^2)	14.95
MDF (km^2)	42.64
OF (km^2)	21.39
Total Forest Cover (%)	0.32
Total Geographical Area (%)	0.15

Stereospermum chelonoides

Geographical Attributes

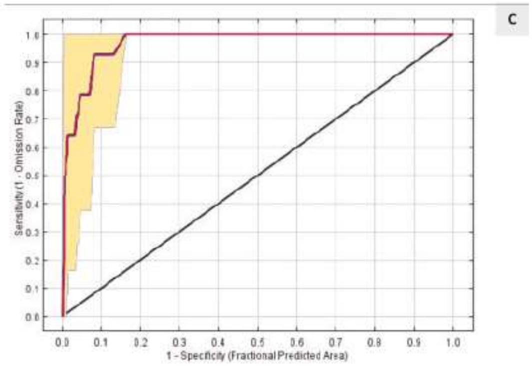
Altitude Range (m)	223-530
Forest Types	3C/C2a, 5B/C1b, 5B/C2
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwa
Maximum Species Occurrence	Haridwar, Nainital

Accuracy Measures

No. of Sample Points	21
AUC	0.971±0.041
Kappa	0.456
TSS	0.859
NMI	−0.002
Environmental Variables	Soil, LULC

Area Occurrence

Estimated Area (km²)	147.23
VDF (km²)	31.37
MDF (km²)	86.48
OF (km²)	29.38
Total Forest Cover (%)	0.61
Total Geographical Area (%)	0.28



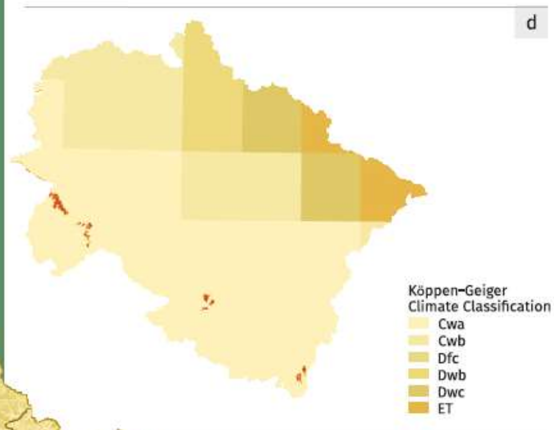


Plate 5.33
Eco-distribution of *Stereospermum chelonoides*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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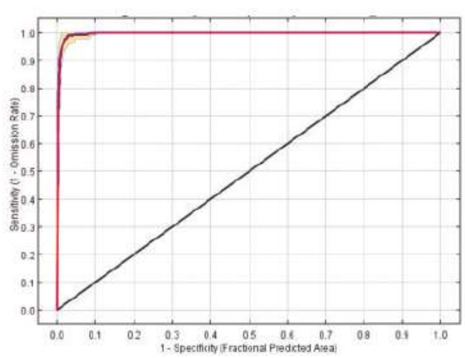
Phanera retusa
District Boundary
Boundary of Forest Division/ Protected Area

Phanera retusa

a

b

c



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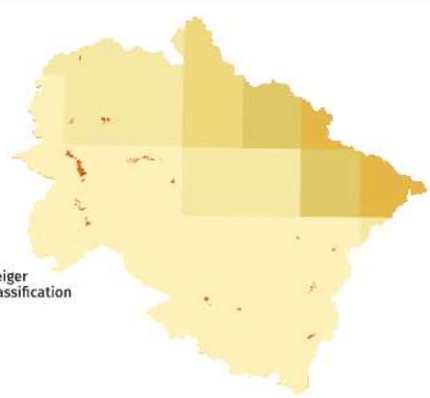

Köppen-Geiger Climate Classification
- Cwa
- Cwb
- Dfc
- Dwb
- Dwc
- ET

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Plate 5.34
Eco-distribution of *Phanera retusa*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range (m)	364–2,105
Forest Types	12/C1a, 9/C1b, 3C/C2a, 5B/c2
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Dehra Dun, Tehri

Accuracy Measures

No. of Sample Points	17
AUC	0.997±0.002
Kappa	0.215
TSS	0.401
NMI	–0.003
Environmental Variables	Soil, Bio 16

Area Occurrence

Estimated Area (km²)	191.94
VDF (km²)	26.92
MDF (km²)	114.12
OF (km²)	50.9
Total Forest Cover (%)	0.79
Total Geographical Area (%)	0.36

Buchanania cochinchinensis

Geographical Attributes

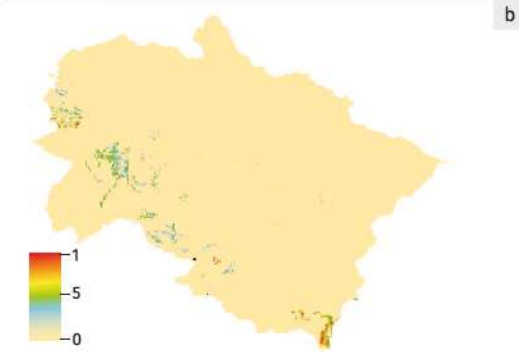
Altitude Range(m)	207–1,690
Forest Types	9/C1b, 3C/C2a, 3C/C3a
Soil Texture	Loamy
Climatic Status	Sub-tropical
KGCC	Cwb
Maximum Species Occurrence	Udham Singh Nagar

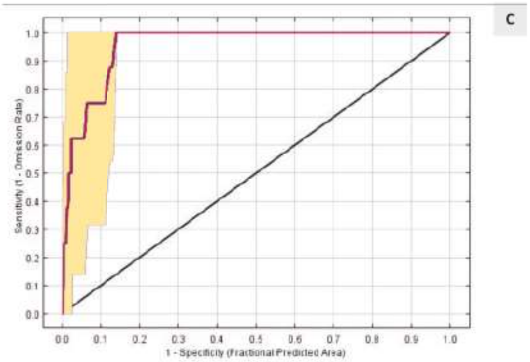
Accuracy Measures

No. of Sample Points	14
AUC	0.953±0.051
Kappa	0.215
TSS	0.919
NMI	−0.002
Environmental Variables	Soil, LULC, Bio 15

Area Occurrence

Estimated Area (km²)	146
VDF (km²)	51.10
MDF (km²)	66.61
OF (km²)	28.90
Total Forest Cover (%)	0.60
Total Geographical Area (%)	0.24





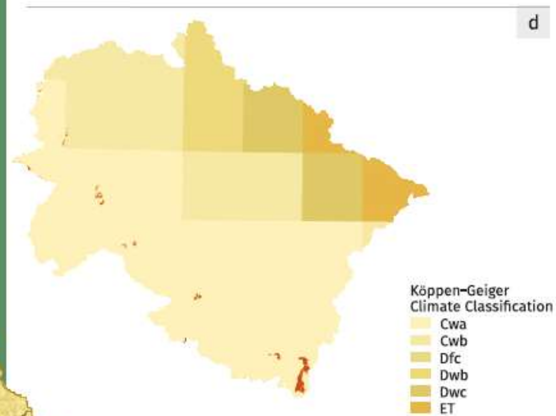


Plate 5.35
Eco-distribution of *Buchanania cochinchinensis*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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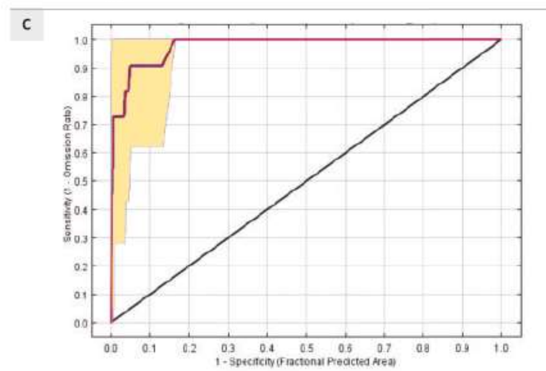
Olea europaea subsp. cuspidata



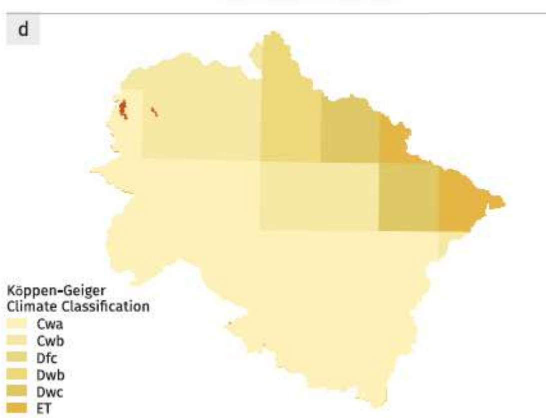


Plate 5.36
Eco-distribution of *Olea europaea* subsp. *cuspidata*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

Geographical Attributes

Altitude Range (m)	1,322–1,906
Forest Types	12/C1a, 9/C1b
Soil Texture	Loamy
Climatic Status	Temperate
KGCC	Cwa
Maximum Species Occurrence	Dehra Dun, Uttarkashi

Accuracy Measures

No. of Sample Points	14
AUC	0.977±0.043
Kappa	0.432
TSS	0.925
NMI	–0.002
Environmental Variables	Soil, Aspect

Area Occurrence

Estimated Area (km²)	56.79
VDF (km²)	3.31
MDF (km²)	11.34
OF (km²)	42.14
Total Forest Cover (%)	0.23
Total Geographical Area (%)	0.11

Ulmus wallichiana

Geographical Attributes

Altitude Range (m)	1,585–2,471
Forest Types	12/C1e, 9/C1b
Soil Texture	Rock outcrops
Climatic Status	Temperate
KGCC	Cwb
Maximum Species Occurrence	Uttarkashi

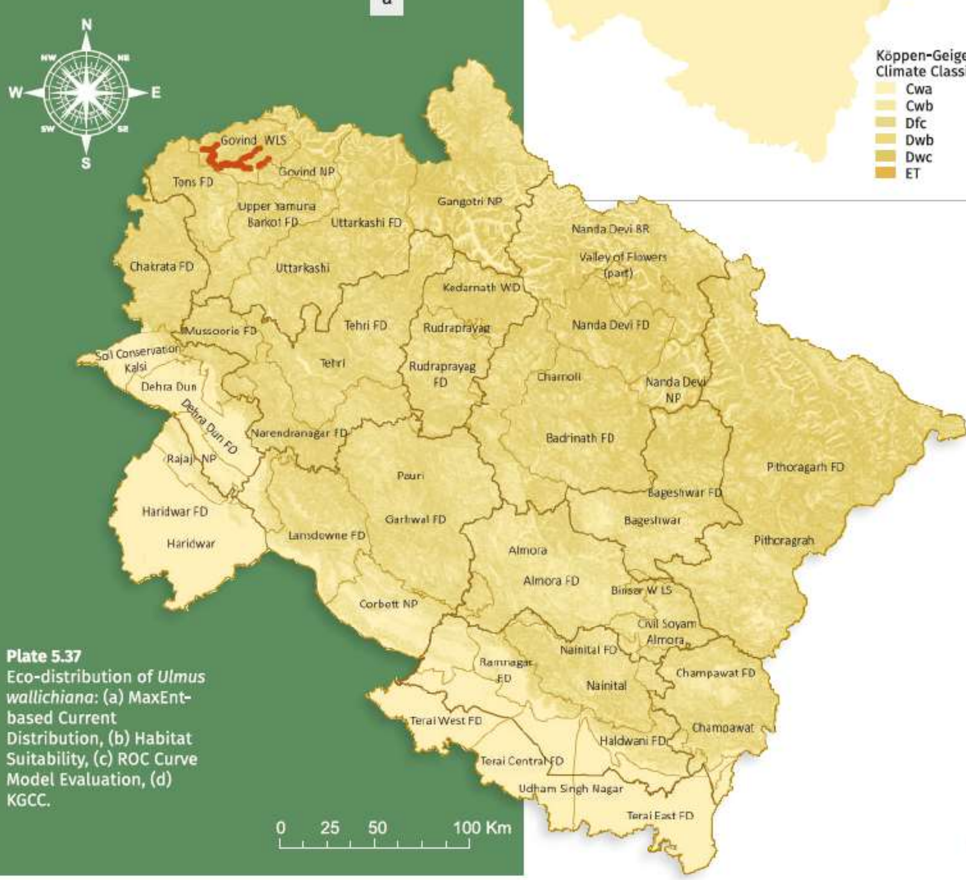
Accuracy Measures

No. of Sample Points	14
AUC	0.995±0.004
Kappa	0.287
TSS	0.860
NMI	-0.002
Environmental Variables	Bio 15, Wind

Area Occurrence

Estimated Area (km²)	33.49
VDF (km²)	9.84
MDF (km²)	15.65
OF (km²)	7.99
Total Forest Cover (%)	0.14
Total Geographical Area (%)	0.06

a



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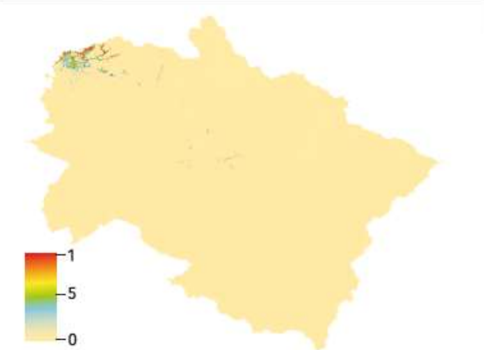

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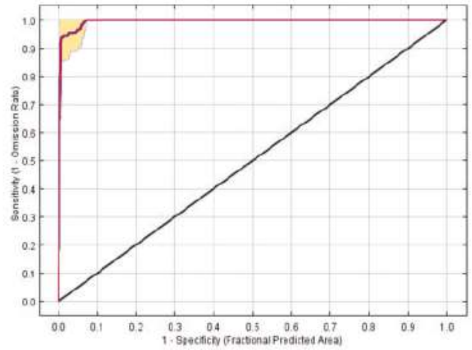

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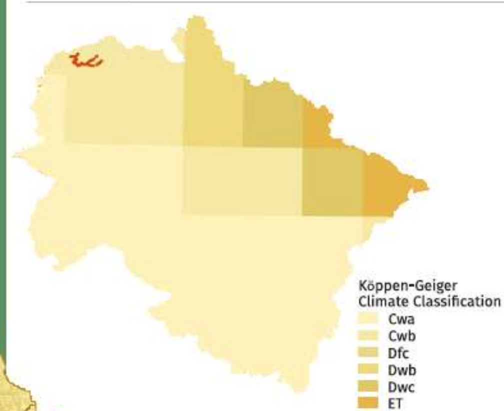

Plate 5.37
Eco-distribution of *Ulmus wallichiana*: (a) MaxEnt-based Current Distribution, (b) Habitat Suitability, (c) ROC Curve Model Evaluation, (d) KGCC.

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5.7.2

Localized Distribution Map of Thirteen FGR Species

A total of 13 species belonging to 12 families were distributed across nine forest sub-types in accordance to few geo-coordinates recorded in Uttarakhand Himalayas. Further, in FTM, such as 12/C1, 9/C1b, 3C/C2a, 3C/C3a, 5B/C1, and 5B/C2 recorded maximum of eight species, whereas five species were recorded in 9/C1a and 14/C1b (Plate 5.38 to 5.50). The vastly distributed species in accordance to FTM were *Elaeodendron glaucum* (Celastraceae), *Trema orientalis* (Cannabaceae), and *Madhuca longifolia* (Sapotaceae) which mostly belongs to the sub-tropical climatic regimes. The unique species *Juniperus polycarpos* (Cupressaceae) belongs to sub-alpine climatic region (Table 5.6; Plate 5.38 to 5.50).

Overall altitudinal range of the species under this class varied from 222 to 2,516 m and ecogeographic distribution maps revealed an actual occurrence area of 192.62 km^2 for 13 species (Table 5.6), with maximum and minimum occurrence under PAs were observed for *B. serrata* (99.75 per cent) and *A. odoratissima* (13.01 per cent), respectively. Interestingly, maximum (32.13 km^2) and minimum (3.14 km^2) values of area were recorded for *T. orientalis* and *Cochlospermum religiosum* in Dehra Dun and Haridwar district, respectively (Fig. 5.5).

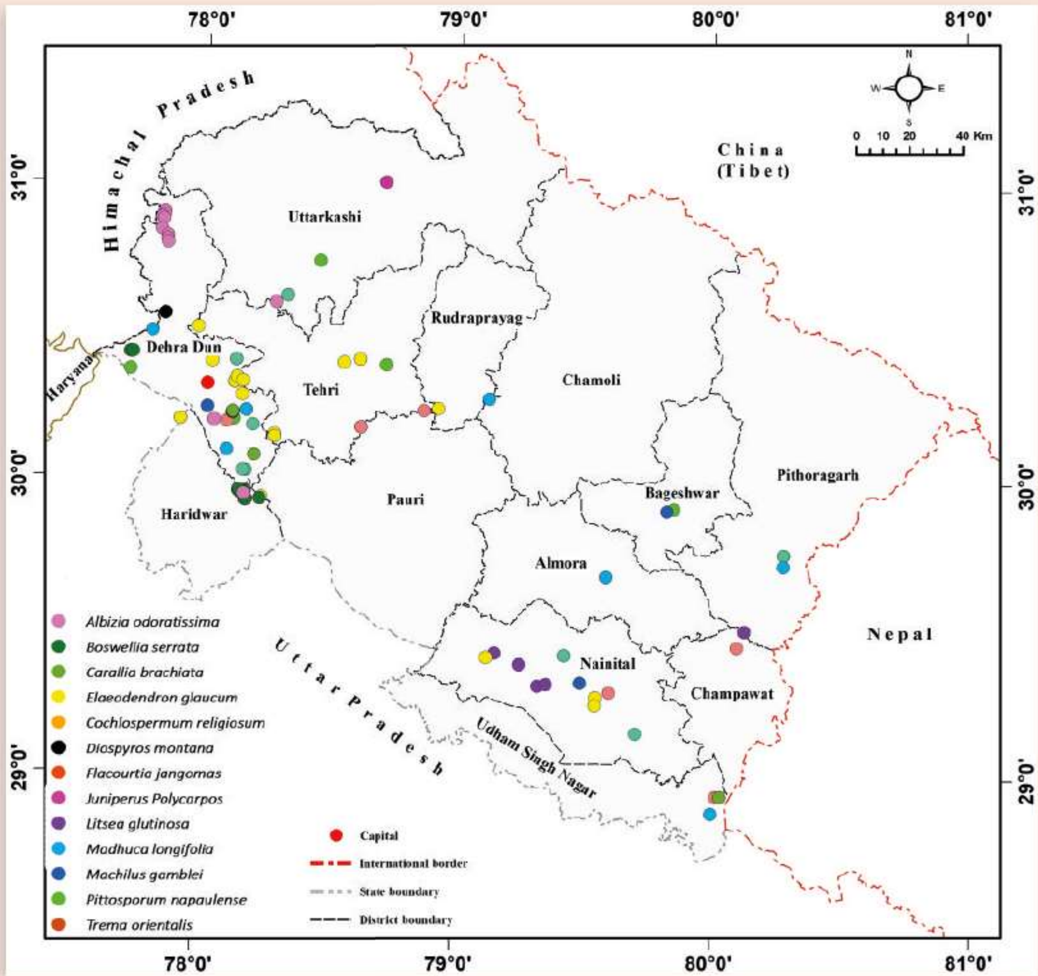

Fig. 5.5 Localized Ecogeographic Distribution of Thirteen Species Having <10 Geo-coordinates

Albizia odoratissima

Albizia odoratissima
District Boundary
Boundary of Forest Division/ Protected Area

N NW NE W E SW SE S

0 25 50 100 Km

Plate 5.38
Point Localized Map of
Albizia odoratissima

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Boswellia serrata

N NW NE W E SW SE S

0 25 50 100 Km

Boswellia serrata
District Boundary
Boundary of Forest Division/ Protected Area

Plate 5.39
Point Localized Map of
Boswellia serrata

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Uttarakhand State

Carallia brachiata

- *Carallia brachiata*
- District Boundary
- Boundary of Forest Division/ Protected Area

Plate 5.40
Point Localized Map of *Carallia brachiata*

Cochlospermum religiosum

- *Cochlospermum religiosum*
- District Boundary
- Boundary of Forest Division/ Protected Area

N E S W NW NE SW SE

0 25 50 100 Km

Plate 5.41 -
Point Localized Map of *Cochlospermum religiosum*

Diospyros montana

Diospyros montana
District Boundary
Boundary of Forest Division/ Protected Area

N NE E SE S SW W NW

0 25 50 100 Km

Plate 5.42
Point Localized Map of
Diospyros montana

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Elaeodendron glaucum

N NE E SE S SW W NW

0 25 50 100 Km

Elaeodendron glaucum
District Boundary
Boundary of Forest Division/ Protected Area

Plate 5.43
Point Localized Map of
Elaeodendron glaucum

Flacourtia jangomas

- *Flacourtia jangomas*
- District Boundary
- Boundary of Forest Division/ Protected Area

Plate 5.44
Point Localized Map of
Flacourtia jangomas

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Establishment of Center of Excellence on Forest Genetic Resources (CoE-FGR)

Uttarakhand State

Juniperus polycarpos

- *Juniperus polycarpos*
- District Boundary
- Boundary of Forest Division/ Protected Area

N
W
E
S
0 25 50 100 Km

Plate 5.45
Point Localized Map of
Juniperus polycarpos

Litsea glutinosa

Litsea glutinosa
District Boundary
Boundary of Forest Division/ Protected Area

Plate 5.46
Point Localized Map of
Litsea glutinosa

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Machilus gamblei

Machilus gamblei
District Boundary
Boundary of Forest Division/ Protected Area

Plate 5.47
Point Localized Map of
Machilus gamblei

Madhuca longifolia

- *Madhuca longifolia*
- District Boundary
- Boundary of Forest Division/ Protected Area

0 25 50 100 Km

Plate 5.48
Point Localized Map of
Madhuca longifolia

Pittosporum napaulense

- *Pittosporum napaulense*
- District Boundary
- Boundary of Forest Division/ Protected Area

0 25 50 100 Km

Plate 5.49
Point Localized Map of
Pittosporum napaulense

Trema orientalis

Trema orientalis
District Boundary
Boundary of Forest Division/ Protected Area

Plate 5.50
Point Localized Map of
Trema orientalis

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Table 5.5 : MaxEnt Model-Based Eco-Distribution Mapped Details of Prioritized 37 FGR Species of Uttarakhand Himalayas

Sr. No.	Species	No of Points	Altitude Range	Forest Sub-Types	Soil Texture	AUC	Climatic Status	KGCC	Kappa	TSS
Class-I (>80 Geo-coordinates; a Total of 11 species; (Plate 5.1-5.11)										
1.	*Myrica esculenta*	800	896-2,289	12/C1a, 9/C1b	Loamy	0.927± 0.025	Temperate	Cwa	0.407	0.719
2.	*Rhododendron arboreum*	750	1,145-3,312	12/C1a, 12/C1e, 12/C2a, 12/C2b, 12/C2c 9/C1b, 15/C1	Loamy	0.932± 0.031	Sub-Alpine	Cwb	0.409	0.744
3.	*Quercus semecarpifolia*	589	2,249-3,652	12/C2b, 12/C2c	Loamy	0.961± 0.018	Sub-Alpine	Cwb	0.553	0.723
4.	*Bombax ceiba*	574	203-1,865	3C/C2a, 3C/C2c, 3C/C3a, 3C/DS1 5B/C1a 5B/C1b, 5B/C2, 5/1S2	Loamy	0.870± 0.044	Sub-Tropical	Cwb	0.346	0.727
5.	*Taxus wallichiana*	365	2,192-3,432	12/C1e, 12/C2b, 14/C1a	Rock Outcrops	0.952± 0.046	Temperate	Cwb	0.431	1.788
6.	*Juglans regia*	162	1,275-2,987	12/C1, 12/C1b	Loamy	0.884± 0.091	Temperate	Cwb	0.432	0.705
7.	*Acer caesium*	117	2,288-3,653	12/C1e, 12/C1f, 12/C2c	Loamy	0.967± 0.068	Temperate	Cwb	0.512	0.853
8.	*Oroxylum indicum*	94	207-1,690	5B/C1a, 5B/C2	Loamy	0.895± 0.104	Sub-Tropical	Cwa	0.247	0.736
9.	*Quercus glauca*	87	842-2,205	12/C1a, 12/C1e, 9/C1b	Loamy	0.928± 0.099	Temperate	Cwa	0.420	0.769
10.	*Quercus lanata*	83	1,526-2,454	12/C1a, 12/C1b	Loamy	0.969± 0.040	Temperate	Cwa	0.595	0.856
11.	*Ougeinia oojeinensis*	81	307-1,735	9/C1a, 5B/C2	Loamy	0.800± 0.105	Sub-Tropical	Cwa	0.195	0.687
	Total	**3,702**	-	-	-	-	-	-	-	-
Class-II (35-<80 Geo-coordinates; a Total of 12 species; (Plate 5.12-5.23)										
1.	*Pterospermum acerifolium*	79	329-1,076	3C/C2a	Loamy Skeletal	0.986± 0.041	Sub-Tropical	Cwa	0.508	0.794
2.	*Betula utilis*	73	2,817-3,806	14/C1a, 14/C1b	Rock Outcrops	0.981± 0.029	Sub-Alpine	Cwb	0.701	0.786
3.	*Populus ciliata*	73	879-3,234	12/C1a, 9/C1b	Loamy	0.919± 0.162	Temperate	Cwb	0.414	0.745
4.	*Terminalia chebula*	73	222-1,602	9/C1b, 3C/C2a, 3C/C2c, 5B/C2	Loamy	0.843± 0.153	Sub-Tropical	Cwa	0.26	0.832
5.	*Hymenodictyon orixense*	59	223-1,207	5B/C2	Loamy	0.875± 0.0198	Sub-Tropical	Cwa	0.429	0.901
6.	*Prunus cerasoides*	46	1,320-2,954	12/C1a, 12/C1d, 9/C1b	Loamy	0.844± 0.177	Temperate	Cwa	0.363	0.814

Ground Based Validation Points (%)	Environmental Variables	Estimated Area (km^2)	VDF (km^2)	MDF (km^2)	OF (km^2)	Total Geographic Area (%)	Total Forest Cover (%)	(%) Occurrence in the PA	Maximum Occurrence Species (Districts)
92.59	Vap, Bio 8	477.26	111.17	260.52	105.57	0.89	1.90	0.75	Almora, Pauri, Nainital
88.89	Bio 7, Soil, Vap	617.48	167.48	320.75	129.25	1.15	2.54	14.90	Champawat, Pauri, Pithoragarh
85.33	Bio 14, Bio 7	832.4	214.15	512.47	105.79	1.56	3.43	21.99	Chamoli, Pithoragarh, Uttarkashi
80.25	Bio 9, Slop	716.9	54.63	355.68	306.59	1.34	2.95	33.53	Nainital, Pauri
90.48	Bio 19, Soil	545.86	147.99	336.58	61.29	1.02	2.25	27.67	Uttarkashi, Chamoli
84.07	Soil, Vap, Bio 1	204.34	39.93	124.96	39.45	0.38	0.84	15.88	Uttarkashi, Pithoragarh
87.50	Bio 1, Bio 6, Soil	183.97	35.7	122.91	25.36	0.34	0.76	33.70	Uttarkashi, Pithoragarh
85.71	Wind, Soil	286.51	43.28	118.48	132.75	0.53	1.17	14.18	Dehra Dun, Nainital
88.89	Soil, Bio 1, Alt	184.26	33.93	96.77	53.56	0.34	0.76	9.53	Chamoli, Pithoragarh
89.65	Soil, Vap, Alt	169.84	50.47	85.91	33.46	0.32	0.70	5.37	Pithoragarh, Nainital
90.00	Soil, Bio 2 Bio 1	384.73	69.71	194.4	120.62	0.72	1.58	14.67	Nainital, Bageshwar
-	-	**4,611.56**	**968.44**	**2,529.43**	**1,113.69**	**8.62**	**18.98**	**19.09**	-
83.33	Bio 14, Vap, Alt	217.55	74.96	97.97	44.62	0.41	0.90	25.20	Dehra Dun, Pauri
91.15	Bio 19, Soil, Bio 14	305.16	11.75	241.14	52.27	0.57	1.26	92.93	Uttarkashi, Pithoragarh
83.33	Soil, Vap	237.27	37.36	156.61	43.3	0.44	0.98	24.52	Uttarkashi, Tehri
77.27	Soil, Bio 1, Bio 2	262.89	64.96	145.92	52.01	0.49	1.08	22.96	Nainital, Haridwar
83.33	Soil, Bio 1	249.83	67.38	138.39	40.37	0.47	1.03	37.61	Nainital, Pithoragarh
81.12	Soil, Bio 1	185.99	26.77	110.35	48.87	0.35	0.77	2.89	Pithoragarh, Uttarkashi

Sr. No.	Species	No of Points	Altitude Range	Forest Sub-Types	Soil Texture	AUC	Climatic Status	KGCC	Kappa	TSS
7.	*Cinnamomum tamala*	44	886-2,619	12/C1a, 9/C1b	Loamy	0.902± 0.162	Temperate	Cwa	0.285	0.703
8.	*Abies spectabilis*	40	2,712-3,684	12/C2b, 14/C1a, 14/C1b	Rock Outcrops	0.986± 0.041	Sub-Alpine	Cwb	0.719	0.71
9.	*Alnus nepalensis*	40	1,227-3,044	12/C1a, 12/C1b, 12/C1e, 3.9/C1b	Loamy	0.913± 0.116	Temperate	Cwb	0.364	0.75
10.	*Buxus wallichiana*	40	2,141-2,646	12/C1a, 12/C1b, 12/C1e, 12/C2c	Loamy Skeletal	0.974± 0.058	Temperate	Cwb	0.587	0.832
11.	*Semecarpus anacardium*	38	210-1,447	3C/C2a, 3C/C3a, 5B/C1b, 5B/C2	Loamy	0.910± 0.035	Sub-Tropical	Cwa	0.200	0.818
12.	*Hovenia dulcis*	38	1,218-2,174	12/C1a, 9/C1b	Loamy Skeletal	0.989± 0.010	Temperate	Cwb	0.384	0.884
	Total	**643**	-	-	-	-	-	-	-	-
Class-III (10–<35) Geo-coordinates; a Total of 14 species; (Plate 5.24-5.37)										
1.	*Ficus neriifolia*	34	662-2,371	12/C1a, 12/C1b, 9/C1b, 5B/C2	Loamy	0.845± 0.175	Temperate	Cwa	0.466	0.887
2.	*Carpinus viminea*	32	1,646-2,471	12/C1a, 12/C1b, 12/C1e	Loamy	0.838± 0.206	Temperate	Cwb	0.207	0.902
3.	*Fraxinus micrantha*	31	1,246-2,622	12/C1a, 12/C1b, 12/C1e, 12/C1f	Loamy	0.960± 0.042	Temperate	Cwb	0.658	0.933
4.	*Cornus capitata*	30	1,636-2,118	12/C1a, 12/C1b, 9/C1b	Loamy	0.891± 0.105	Temperate	Cwa	0.425	0.863
5.	*Diploknema butyracea*	30	509-1,526	12/C1a, 9/C1b	Loamy	0.961± 0.059	Temperate	Cwa	0.306	0.764
6.	*Corylus jacquemontii*	26	2,142-3,423	12/2S1, 14/C1b, 13(i)/C2b, 16/C1	Rock Outcrops	0.953± 0.102	Temperate	Cwb	0.532	0.885
7.	*Tsuga dumosa*	24	2,630-3,367	12/C1 d 12/C2 a	Loamy	0.999± 0.000	Temperate	ET	0.941	1.000
8.	*Premna mollissima*	23	346-1,738	9/C1b, 3C/C2a, 5B/C1a, 5B/C2b, 5B/C2	Loamy Skeletal	0.834± 0.058	Sub-Tropical	Cwa	0.052	0.883
9.	*Albizia julibrissin*	22	1,131-2,295	12/C1a, 12/C1d, 9/C1b	Loamy Skeletal	0.928± 0.112	Temperate	Cwb	0.580	0.997
10.	*Stereospermum chelonoides*	21	223-530	3C/C2a, 5B/C2	Loamy 5B/C1b,	0.971± 0.041	Sub-Tropical	Cwa	0.456	0.859
11.	*Phanera retusa*	17	364-2,105	12/C1a, 9/C1b, 3C/C2a, 5B/C2	Loamy	0.997± 0.002	Temperate	Cwa	0.215	0.401

Ground Based Validation Points (%)	Environmental Variables	Estimated Area (km²)	VDF (km²)	MDF (km²)	OF (km²)	Total Geographic Area (%)	Total Forest Cover (%)	(%) Occurrence in the PA	Maximum Occurrence Species (Districts)
84.50	Bio 4, Soil	158.62	43.25	81.79	33.57	0.30	0.65	8.46	Nainital, Bageshwar
80.77	Bio 14, Soil, Bio 8	147.85	8.54	113.37	25.94	0.28	0.61	57.90	Uttarkashi, Rudraprayag
90.00	Bio 15, Bio 5 Bio 6	143.65	34.79	75.43	33.43	0.27	0.59	9.58	Chamoli, Uttarkashi
89.29	Soil, Bio 8	187.57	62.81	95.84	28.92	0.35	0.77	25.64	Uttarkashi, Pithoragarh
77.27	Soil, Altitude	227.91	94.19	117.85	15.87	0.43	0.94	24.78	Nainital, Udham Singh Nagar
85.70	Soil, LULC	77.10	22.67	34.76	19.67	0.14	0.32	43.57	Uttarkashi
-	-	**2,401.39**	**549.43**	**1,409.42**	**438.84**	**4.49**	**9.88**	**33.61**	-
83.33	Soil, Vap, Bio 4	218.25	46.85	113.22	58.18	0.41	0.90	5.77	Bageshwar, Uttarkashi
83.33	Soil, Bio 1 Bio 4	174.26	50.11	90.24	33.9	0.33	0.72	24.46	Bageshwar, Uttarkashi
85.71	Bio 14, Soil, Alt	198.47	67.95	103.26	27.26	0.37	0.82	18.92	Pithoragarh, Bageshwar
85.71	Soil, Bio 10 LULC	146.28	56.17	56.07	34.04	0.27	0.60	10.67	Uttarkashi, Champawat
75.00	Soil, Vap	200.10	-	-	-	0.82	0.37	1.05	Pithoragarh
70.00	Soil, Lulc	76.83	9.67	54.33	12.83	0.14	0.32	45.74	Uttarkashi, Pithoragarh
75.00	Soil, Bio 4	15.54	4.59	9.24	1.71	0.03	0.06	72.66	Pithoragarh
80.00	Soil, Bio 1	161.38	45.38	84.24	31.76	0.30	0.66	-	Dehra Dun, Nainital
85.71	Bio 15, Bio 5 Bio 6	78.98	14.95	42.64	21.39	0.15	0.32	30.38	Uttarkashi
80.00	Soil, LULC	147.23	31.37	86.48	29.38	0.28	0.61	69.16	Haridwar, Nainital
85.71	Soil, Bio 16	191.94	26.92	114.12	50.9	0.36	0.79	13.10	Dehra Dun, Tehri

Sr. No.	Species	No of Points	Altitude Range	Forest Sub-Types	Soil Texture	AUC	Climatic Status	KGCC	Kappa	TSS
12.	*Buchanania cochinchinensis*	14	207-1,690	9/C1b, 3C/C2a, 3C/C3a	Loamy	0.953± 0.051	Sub-Tropical	cwb	0.215	0.919
13.	*Olea europaea subsp cuspidata*	14	1,322-1,906	12/C1a, 9/C1b	Loamy	0.977± 0.043	Temperate	Cwa	0.432	0.925
14.	*Ulmus wallichiana*	14	1,585-2,471	12/C1e, 9/C1b	Rock Outcrops	0.995± 0.004	Temperate	Cwb	0.287	0.86
	Total	**332**	-	-	-	-	-	-	-	-

Note: For nomenclature on forest sub-type, refer Chapter-2

Table 5.6 : Localized Ecogeographic Distribution Details of Thirteen FGR Species of Uttarakhand Himalayas

Sr. No.	Species	Total GPS Points	Geographical Extension		
			Latitude	Longitude	Altitude (m)
1.	*Albizia odoratissima*	9	29°56'54.736"-30°49'16.605"	78°10'31.496"-77°51'0.922"	286-1,787
2.	*Boswellia serrata*	3	29°56'53.6"-30°25'26.313"	78°11'34.963"-77°43'11.045"	297-415
3.	*Carallia brachiata*	5	28°56'34.48"-30°13'47.05"	80°2'17.31"-78°7'13.174"	222-542
4.	*Cochlospermum religiosum*	1	29°55'56.498"	78°10'44.592"	430
5.	*Diospyros montana*	4	30°13'44.086"-30°33'29.507"	78°7'18.582"-77°50'53.594"	556-828
6.	*Elaeodendron glaucum*	9	30°12'12.608"-30°20'1.773"	77°55'11.074"-78°9'34.204"	566-1,390
7.	*Flacourtia jangomas*	7	28°56'31.01"-29°26'54.775"	80°1'8.278"-80°6'0.357"	236-1,659
8.	*Juniperus polycarpos*	1	31°0'55.429"	78°42'30.99"	2,516
9.	*Litsea glutinosa*	5	29°25'23.37"-29°19'7.969"	79°9'33.485"-79°21'35.283"	396-609
10.	*Machilus gamblei*	3	30°14'40.126"-29°54'31.798"	78°1'18.037"-79°49'30.74"	562-975
11.	*Madhuca longifolia*	9	28°53'7.569"-29°41'9.813"	80°0'2.747"-79°35'27.151"	228-1,318
12.	*Pittosporum napaulense*	5	30°12'17.023"-30°23'46.01"	78°7'43.03"-78°43'19.188"	530-1,236
13.	*Trema orientalis*	9	29°57'33.7"-29°25'3.857"	78°9'57.8"-79°25'46.72"	350-2,068

Ground Based Validation Points (%)	Environmental Variables	Estimated Area (km^2)	VDF (km^2)	MDF (km^2)	OF (km^2)	Total Geographic Area (%)	Total Forest Cover (%)	(%) Occurrence in the PA	Maximum Occurrence Species (Districts)
90.00	Soil, LULC Bio 15	146	51.10	66.61	28.90	0.24	0.60	10.72	Udham Singh Nagar
75.00	Soil, Aspect	56.79	3.31	11.34	42.14	0.11	0.23	-	Dehra Dun, Uttarkashi
90.91	Bio 15, Wind	33.49	9.84	15.65	7.99	0.06	0.14	99.96	Uttarkashi
-	-	**1,845.54**	**418.21**	**847.44**	**380.38**	**3.45**	**7.59**	**19.34**	-

	Total Occurrence Area (km^2)	% Occurrence in the PA	Maximum Species Occurrence (District)	Forest Sub-Types
	24.14	13.01	Dehra Dun	3C/C2a Moist Shiwalik Sal Forest
	9.42	99.75	Dehra Dun	5B/C2 Northern Dry Mixed Deciduous Forest
	7.00	-	Dehra Dun	3C/C3a West Gangetic Moist Mixed Deciduous Forest, 3C/C2a Moist Shiwalik and Teak Plantation
	3.14	-	Haridwar	Plantation
	9.42	-	Dehra Dun	3C/C2a Moist Shiwalik Sal Forest, 3C/C3a West Gangetic Moist Mixed Deciduous Forest
	26.95	-	Tehri	3C/C2a Moist Shiwalik Sal Forest, 5B/C1a Dry Shiwalik Sal Forest, 5B/C1b Dry Plains Sal Forest, 9/C1b Upper or Himalayan Chir Pine Forest, 12/C1a Ban Oak Forest (*Q. incana*)
	18.01	-	Nainital	3C/C2a Moist Shiwalik Sal Forest, 3C/C3a West Gangetic Moist Mixed Forest, 5B/C2 Northern Dry Mixed Deciduous Forest, 9/C1a Lower or Shiwalik Chir Pine Forest
	3.85	-	Uttarkashi	14/C1b West Himalayan Sub-Alpine Birch
	14.50	23.59	Nainital	3C/C3a West Gangetic Moist Mixed Deciduous Forest, 3C/C2a Moist Shiwalik Sal Forest
	9.70	22.99	Nainital	3C/C2a Moist Shiwalik Sal Forest, 9/C1b Upper or Himalayan Chir Pine Forest, and 12/C1a Ban Oak Forest (*Q. incana*)
	21.04	29.75	Dehra Dun	Plantation, 3C/C2a Moist Shiwalik Sal Forest, 12/C1a Ban Oak Forest (*Q. incana*), 9/C1b Upper or Himalayan Chir Pine Forest, Tropical Riverine Forest, 5B/C2 Northern Dry Mixed Deciduous Forest, Teak Plantation
	13.32	-	Dehra Dun	12/C1a Ban Oak Forest (*Q. incana*), 3C/C3a West Gangetic Moist Mixed Forest, 3C/C2a Moist Shiwalik Sal Forest
	32.13	32.13	Dehra Dun	3C/C2a Moist Shiwalik Sal Forest, 12/C1a Ban Oak Forest (*Q. incana*), Tropical Riverine Forest, 9/C1b Upper or Himalayan Chir Pine Forest, 5B/C1a Dry Shiwalik Sal Forest, and 5B/C1b Dry Plains Sal Forest

5.8
Discussion

The Uttarakhand Himalayas consist of broader forest perspective that represent one of the distinct biomes of the world, and any study under this could have vast applicability across the globe in case of forestry research. The present study represents the first ever attempt to model the distribution scenario of 50 targeted FGR species across the Uttarakhand State as a pilot effort, whose impacts could be linked further for species association, topographical factors, and spatial distribution under climate change, and provides valuable baseline data. This section has been divided into four subsections.

5.8.1.
Precision Measures of MaxEnt Model

AUC is a frequently used approach for estimating the predictive accuracy of distributional models derived from presence–absence data (Fielding and Bell, 1997; Lobo *et al.*, 2008), and comprehensively used in the various research fields, such as health, medical, agriculture, demographic, forestry, etc. (Pearce and Ferrier, 2000; Manel *et al.*, 2001; McPherson *et al.*, 2004). For instance, 10 true presences are compared to 90 absences, and a model predicts species presences in 20 sites (a 100 per cent over prediction), then the sensitivity is 1, the specificity is 0.89, and the AUC is considered excellent (Lobo *et al.*, 2008). The results of present studies on 37 species were consistent with the model's execution, as evidenced by the AUC curve (~1.0, i.e., 0.84-0.99). (Fielding and Bell, 1997; Young *et al.*, 2011). Under this, Class I (0.80-0.96) was dominated by *M. esculenta*, followed by *R. arboreum, Q. semecarpifolia*, and *B. ceiba*; Class II (0.84-0.98) was dominated by *P. acerifolium*, followed by *B. utilis, P. ciliata*, and *T. chebula*; and Class III (0.83–0.99) was dominated by *F. neriifolia*, followed by *C. viminea, F. micrantha*, and *C. capitata*. These findings were in concurrence with the study conducted on *Ilex khasiana* (0.97) in northeastern India (Adhikari *et al.*, 2012), *Sapium sebiferum* (~1) in Western Himalayas (Jaryan *et al.*, 2013), *Justicia adhatoda* (0.92) in Shiwalik Hills in Doon Valley (Yang *et al.*, 2013), *Hyptis suaveolens* (0.86) in India (Padalia *et al.*, 2014), and *M. esculenta* (0.95) in Kumaun Himalayas (Shankhwar *et al.*, 2017), *Q. lanata* and *M. esculenta* (0.89 and 0.84) in the Western Himalayas (Bhandari *et al.*, 2020). Notably, an AUC value of 0.8 is typically considered to be an excellent performance model, whereas AUC values >0.9 are extremely strong performance models (Swets, 1988). The AUC values pertaining to the training data ranged mostly from 0.8-0.9, which revealed the MaxEnt is considered as a good SDM model, implying that 37 species have a ~90 per cent chances of complete distribution in Uttarakhand Himalayas.

In ecology, the most widely used metric for determining the accuracy of presence–absence prediction modelling are Cohen's Kappa (*K*) and TSS (Shao and Halpin 1995; Manel *et al.*, 2001; Loiselle *et al.*, 2003; Petit *et al.*, 2003; Berg *et al.*, 2004; Parra *et al.*, 2004; Pearson *et al.*, 2004; Rouget *et al.*, 2004; Segurado and Araujo, 2004; Allouche *et al.*, 2006). The *K* ranges from -1 to +1, with +1 indicating excellent fit and 0 or less indicating no better than random performance (Cohen, 1960). Whereas TSS corrects for prevalence reliance while preserving all Kappa benefits, values ranging from -1 to +1, with +1 indicating perfect agreement and 0 or less indicating no better than random performance (Allouche *et al.*, 2006). This study provided *K* and TSS between 0.26-0.94 and 0.68-1.78, with Class I (*K*=0.19-0.59; TSS=0.68-1.78) dominated by *M. esculenta*; Class II (*K*=0.20–0.71; TSS=0.70–0.90) by *P. acerifolium*; and Class III (*K*=0.05 to 0.94; TSS=0.40–1.00) by *F. neriifolia*.

5.8.2.
Environmental Variables and Soil

The relative importance of 26 climatic variables was estimated by analyzing the environmental variable response curves of significance in 37 species. Since species reacted differently to climatic datasets, the most prominent variables, namely soil, annual mean temperature (Bio 1), and precipitation of the driest month (Bio 14) were observed to appear in all the 3 classes, influencing plant growth and distribution (Zhong *et al.*, 2010). Other variables, such as Bio 4, Bio 5, Bio 6, Bio 10, Bio 15, Bio 16, wind, LULC, altitude and aspect for Class I; Bio 4, Bio 5, Bio 6, Bio 8, Bio 10, Bio 15, LULC, altitude and water vapor for Class II; and Bio 4, Bio 5, Bio 6, Bio 10, Bio 15, Bio 16, wind, LULC, altitude and aspect or Class III, were shown to play an important impact in influencing the distribution of species in the Uttarakhand Himalayas.

It is important to note that precipitation (annual, warmest quarter, wettest month) and temperature have a significant impact on the distribution pattern, although some of the Himalayan species does not require much water and acclimatize for day-night variation in temperature (Bhandari *et al.*, 2020). The results showed that Bio 14 and Bio 1 were the primary bioclimatic factors explaining variations in species distribution pattern. For instance, if extreme precipitation conditions over the year influence a species potential range, then variable Bio 14 was seeming to be suitable for the species with an overall rainfall range variation of 20-140 mm. Likewise, Bio 1 was significant in habitat appropriateness for species with an optimal annual mean temperature of 22-30°C, which approximates the total energy inputs for an ecological site. Species distribution habitat suitability in *A. spectabilis, B. utilis, Q. semecarpifolia,* and *R. arboreum* was more pronounced at increase in Bio 14 probability threshold at 200 mm. Furthermore, between 20 and 24°C, there was a positive link between species abundance and Bio 1, beyond which further temperature increases have a lesser habitat suitability prediction. Compared to the present study, two variables (Bio 1 and Bio 14) have a substantial impact on the distribution of *Stipa purpurea* of the Tibetan highlands (Ma and Sun, 2018).

Secondly, soil type appears to play a major role in habitat suitability for the species. Soil is a vital non-renewable resource that exists in a wide variety around the world. Different soil kinds have different characteristics and physical features. It is critical for ecosystems as well as human existence and society. As a result, maintaining soil functions and characteristics is critical for the ecosystems and human survival (Blum, 1993; Drexhage, 2001; De Groot *et al.*, 2002). Present research has identified soil as a crucial edaphic element in determining the distribution of 37 species in the Uttarakhand Himalayas, as it shows that soil conservation strategy should be used to enrich plant cover that needs to be preserved. Ideal soil types for Class I were dominated by sandy-skeletal on very steep slope with severe erosion and mod; stoniness, rock outcrops, followed by calcareous loamy with mod; erosion and slight stoniness on steep slopes; and calcareous sandy on gentle slopes; loamy on steep slope with severe erosion; rock-outcrops, fragmental on steep slope, loamy on steep slope with severe erosion. Class II was dominated by Loamy with mod; Erosion, loamy-skeletal on steep slopes; Calcareous loamy with mod; Erosion and slight stoniness, Calcareous sandy on gentle slopes followed by Loamy with severe erosion and slight stoniness; Loamy on steep slope, calcareous sandy skeletal with mod; Erosion and mod; Stoniness, calcareous sandy on mod; Slopes, rock outcrops, loamy skeletal on very steep slopes. However, the Class III was dominated by Calcareous loamy with mod; Erosion and slight stoniness, calcareous sandy on gentle slopes followed by Rock outcrops, fragmental on steep slope, loamy with mod; Erosion, loamy skeletal on steep slope and calcareous sandy-skeletal with mod; Erosion and mod; and Stoniness, Calcareous sandy on mod. Notably, the edaphic features were used to identify all potential combinations of soil types and vegetation, and then assigned a suitable recharge estimate to each combination (Fayer and Simmons, 1995), where species pertains to habitat in a particular soil zone.

Overall, study concluded that, while various bioclimatic variables may influence plant species richness, the soil, Bio 1, and Bio 14 are the most important bioclimatic variables in the current study, which might have been influenced by the topographic features of the Himalayan terrain (Sahragard and Chahouki, 2015).

5.8.3.

Ecogeographic Distribution, Topographic Conditions (Elevation), and KGCC Maps

The projected distributional extent and PAs coverage of 37 species as established by the MaxEnt predication modeling-based on the extensive field surveys were about 8,858.49 km^2 and 2,043.72 km^2 respectively. In MaxEnt, species distribution modeling is directed by spatial coordinates and ecological factors (Phillips and Dudik, 2008). Previous studies in India included the species distribution modeling for medicinally important species namely, *Berberis aristata* (Ray *et al.*, 2011), *J. adhatoda* (Yang *et al.*, 2013), and *Brucea mollis* (Borthakur *et al.*, 2018); endangered species, such as *Gymnocladus assamicus* (Menon *et al.*, 2010), *Ilex khasiana* (Adhikari *et al.*, 2012), and *Neottia cordata* (Tsiftsis *et al.*, 2019), invasive species like *Hyptis suaveolens* (Padalia *et al.*, 2014), and the bamboo *Yushania maling* (Srivastava *et al.*, 2018) along with tree species like *Fagus sylvatica* (Castaño-Santamaría *et al.*, 2019). The PAs are generally established in areas known to have high biodiversity, and while they are relatively new, they were carefully selected with expert knowledge (Newbold *et al.*, 2009). Alternatively, effective ecosystem management within PAs may be one of the reasons for older reserves of genetic resources with high biodiversity (Thomas and Gillingham, 2015). PAs covers about 12% of the global terrestrial habitat, but many of them fail to protect biodiversity and ecological processes (Seiferling *et al.*, 2012); and our study also revealed that only 23.07% of the species estimated areas under PAs. Thus, highlighted the significance and importance of probable conservation and management plan through ecogeographic mapping of FGRs.

Topographic conditions can affect plant habitat distribution through changing soil and other biological factors (Biglouei *et al.*, 2008). As a result, different species establish themselves in a specific elevation range based on their ecological requirements. The impact of altitude on plant habitat distribution has been extensively studied in various biomes of the world (Arekhi *et al.*, 2010; Chahouki *et al.*, 2010; Hosseini *et al.*, 2013; Sahragard and Chahouki, 2015). The topographic conditions play a larger role in species distribution in Uttarakhand Himalayas. The highest elevation zone for species distribution were recorded for *A. caesium* (3,653 m) in Uttarkashi, *T. wallichiana* (3,432 m) in Chamoli, and *R. arboreum* (3,234 m) in Pithoragarh under Class I. In comparison to lower altitudes, these species seem to be widely distributed at higher elevations. This is due to the lower temperature and increased atmospheric moisture in high altitudinal environments. Further, in Uttarkashi, Pithoragarh, Chamoli, Bageshwar, and Nainital districts, the density values of these species were profoundly higher. Study results showed that the species favours high altitudinal environments, though range of the mapping species varied from 203-3,806 m. Topographic parameters were found to be strongly related to species distribution and forest composition in China's mountain forests (Zhang *et al.*, 2016).

A topographic slope's compass orientation, commonly measured in degrees from north continuous elevation surfaces generally used to generate aspects (Malaperdas and Panagiotidis, 2018). The aspect value represents the slope's compass direction (Magesh *et al.*, 2011). Notably, the species of Class I, such as *B. ceiba, O. indicum, M. esculenta, Q. glauca,* and *O. oojeinensis* grow on the southern aspect at lower altitudes, but grow on all other aspects at higher altitudes. Class II species, namely *P. acerifolium, P. ciliata, T. chebula, H. orixense, C. tamala,* and *S. anacardium* grow on the southern aspect at lower elevations, but grows on all aspects at higher altitudes. Class III categorized species, such as *F. neriifolia, D. butyracea, P. mollissima, S. chelonoides, P. retusa*, and *B. cochinchinensis* grow on the southern aspect at lower altitudes but grow on all aspects at higher altitudes. Since sun shines directly on the slope from east to west on an Earth's surface feature like mountain and hills, the south facing slope becomes warmer than the east-and north facing slopes, which are usually having high moisture content and low evaporation rate (Arefin, 2020). This elaborates the role of slope and aspect in wider range species and inform about the scattered distribution of some of the mountain species in the Himalayas.

Climate change has a direct impact on ecosystem processes and functioning, as well as species distribution. Importantly, the KGCC system has been used to identify climate patterns in the past. Based on annual cycles of surface air temperature and precipitation, the KGCC maps were created which has a stronger link with biome and soil type distribution than other human expertise-based climate mapping methods and clustering approaches that lack a meteorological basis (Cui *et al.*, 2021). The species current distribution map was plotted over the KGCC and it was found that the area with elevation ranged from 203-3,806 m mostly occurs in the humid sub-tropical climate (Cwa; C=warm temperate, w=winter dry, and a=hot summer) and sub-tropical highland oceanic climate (Cwb; C=warm temperate, w=winter dry, and b=warm summer monsoon-influenced), and Class III (K=0.05 to 0.94; TSS=0.40–1.00) by *F. neriifolia*.

5.8.4.

Localized Geo-Tagged Mapping

Point occurrence data are available from surveys and numerous other sources (Hijmans *et al.*, 1999; Rowe 2005). Distribution information may be available from surveys, for example, Araújo *et al.*, (2005) built distribution models using data from The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991. In present study, the actual occurrence area of 192.62 km^2 was recorded for 13 species under Category 2. Maximum occurrence of species, namely, *A. odoratissima, B. serrata, D. montana, M. longifolia, T. orientalis, C. brachiate,* and *P. napaulense*, were observed in Dehra Dun district. Notably, the highest elevation zone for species geo-coordinates was recorded for *T. orientalis, F. jangomas*, and *A. odoratissima*. Further, in FTM, 12/C1 type was dominated by species like *M. gamblei, M. longifolia, T. orientalis, E. glaucum,* and *P. napaulense*; and 3C/C2 forest type was dominated by species, such as *A. odoratissima, D. montana*, and *F. jangomas*. The 13 species grow on the southern aspect at lower altitudes.

Overall, the 50 species maps provide vast array of distribution range in the Himalayan climatic regimes. Due to the high economic, ethnobotanical, and ecological significance of forest species distributed in the Himalayas, the study highlighted several starting points to the current situation of mapped species that probably might be rapidly changed under the influence of climatic and non-climatic variables, besides being affected by the local anthropogenic activities.

5.9

Key Messages, Limitations, Recommendations and Priority Actions

Study on the ecogeographic mapping of 50 prioritized species of Uttarakhand as a part of the Pilot Project based on MaxEnt Modeling has provided a valuable insight on the range and population distribution of these priority species. The following section attempts to highlight the key findings, limitations, recommendations and priority actions required for conservation of studied species:

5.9.1.

Key Messages

- MaxEnt Modeling protocol, a free software and user-friendly operational interface based on the presence data of a species and environmental data (both continuous and categorical) used as input variables immensely helps in generating GIS-based ecogeographic maps of species range and population distribution. The MaxEnt prediction accuracy is always stable and reliable, particularly in a situation when there are fewer presence data and small sample sizes. Remotely sensed data not only can be quickly processed and analyzed for vast extent of study area but also can be used for a wide range of research and management purposes. It also reduces the amount of effort required in the inaccessible, rugged terrain, difficult field situations, and harsh climatic conditions. The remote sensing and GIS-based technologies used in the MaxEnt modeling allow repetitive coverage on dynamic variables like land use, vegetation, water, and cropping pattern, and enables convenient collection of data at different scales and resolutions. Ecogeographic maps generated through MaxEnt modeling protocol immensely helps in improved decision making relevant to management of natural resources and conservation programs of RET species. The outputs generated also reduce cost and improve management efficiency. Specific information on forest types and forest cover as categorical data used in ecogeographic mapping improves understanding on the species distribution and communication among multi-agencies by providing the information in the visual format.

- Model based on the maximum entropy approach employed for estimating the distribution and habitat suitability of the species used a set of 27 bioclimatic variables, primarily average monthly climatic data for minimum, maximum and mean for temperature and precipitation over the period of 1970-2000 besides species presence data and variables like altitude, aspect, slope, direct normal irradiance, vapor, wind, land use land cover, and soil. Present study allowed the development of ecogeographic maps of 50 prioritized FGR species with the precise location and distribution range of these species in the varied forest sub-types and administrative units i.e., districts of the Himalayan State of Uttarakhand. These ecogeographic maps along with their area statistics are valuable information for use by concerned DCFs/ DFOs/ PA Managers of respective FDs/ PAs and other stakeholders, particularly in the process of revision of Working Plans/ Management Plans or even formulation of conservation strategy for the RET species.
- Out of 50 prioritized FGR species, 37 species were mapped through MaxEnt prediction-based modeling, whereas rest 13 species as per locations recorded during the field surveys. For 37 species, categorization was done based on the number of geo-coordinates on species presence data. Accordingly, the Class I (>80 geo-coordinates), Class II (35-80 geo-coordinates), and Class III (10 - <35 geo-coordinates) included 11, 12, and 14 species, respectively. Distribution maps for remaining 13 species were developed based on actual presence data and corresponding smaller number of geo-coordinates. Ecogeographic map generated in case of 37 species provided valuable statistics on estimated area, distribution in different forest canopy classes, altitudinal range, prominent environmental variables, maximum occurrence of species in different districts besides values of AUC, KGCC, Kappa, TSS, and percentage representation of geo-coordinates in area of validation.
- The area of estimated range in case of 37 prioritized FGR species ranged from as low as 15.54 km^2 (*Tsuga dumosa*) to 832.4 km^2 (*Q. semecarpifolia*), representing 0.03 per cent to 1.56 per cent of geographical area of the State, and 0.06 per cent to 3.43 per cent of forest cover. Species *viz.*, *Bombax ceiba, Rhododendron arboreum, Taxus wallichiana, Myrica esculenta, Ougeinia oojeinensis, Betula utilis, Oroxylum indicum,* and *Terminalia chebula* had relatively higher extent of distribution range amounting to 716.9 km^2, 617.48 km^2, 545.86 km^2, 477.26 km^2, 384.73 km^2, 305.16 km^2, 286.51 km^2, and 262.89 km^2, respectively. In contrast, species *viz.*, *Albizia julibrisin, Hovenia dulcis, Corylus jacquemontii, Olea europaea subsp. cuspidata,* and *Ulmus wallichiana* had lower extent of their distribution range amounting to 78.98 km^2, 77.10 km^2, 76.83 km^2, 56.79 km^2, and 33.49 km^2, respectively. In case of 13 species having localized eco-distribution, the total occurrence area ranged from as low as 3.14 km^2 (*Cochlospermum religiosum*) to 32.13 km^2 (*Trema orientalis*). Species like *Diospyrus montana, Boswellia serrata, Madhuca longifolia,* and *Albizia odorattisima* recorded occurrence area of 9.42 km^2, 9.42 km^2, 21.04 km^2, and 24.14 km^2, respectively. In majority cases, the values of AUC were above 0.8 indicating higher accuracy of prediction mapping. Likewise, in most instances, the maximum points have fallen in the prediction threshold with values >80 per cent. Districts *viz.*, Pithoragarh, Uttarkashi, Nainital, Bageshwar, Champawat, Dehra Dun and Pauri recorded relatively higher number of species

5.9.2.

Limitations

MaxEnt Model protocol uses large amounts of datasets at a given time, often leading to issues related to handling of intricate data, risk of generalization, and difficulties in terms of interpretation besides demands large storage capacity and efficient computer processing systems. Generally, data on forest types, forest cover and other environmental variables obtained from different sources differ in spatial resolution sizes and projected parameters reducing the accuracy of model outputs. The procurement of RS and agency specific categorical data in several instances is a protracted, cumbersome and expensive process. GIS modeling necessitates difficult and complicated overlaying of multiple layer data that requires experienced professionals in the field. The SDMs have been developed specifically for use when data on species is inadequate so as to generate genuine species distribution maps or to forecast reliable extrapolations. However, SDMs on account of theoretical problems and inadequate researches have resulted in lower application of SDM outputs, decision making, and environmental licensing. In case of MaxEnt outputs, it is difficult to compare with other algorithms as it provides environmental appropriateness/ suitability in the context of a species rather than the projected probability of occurrence. Moreover, the MaxEnt logistic output is solely based on the prevalence assumption in view of environmental suitability rather than an actual extensive and intensive field level assessments and estimation.

5.9.3.

Deliverables and Applications of Species Distribution Mapping

The Pilot Project has facilitated for the first time to develop and generate species distribution databases for 50 prioritized species concurrently compared to similar efforts by various international platforms/ agencies/ networks (e.g., FGRMN, IPCC, EUFORGEN, IUFRO, IUCN, etc.). The varied outputs have yielded valuable quantitative baseline information for future comparison in the event of land use changes, developmental activities and climate change. Every country values its forest genetic resources, especially the ecogeographic mapping of species of ecological and economic significance published in the form of international peer reviewed research papers of global importance offer an opportunity to the international agencies, policy makers and researchers to develop an insight on the condition of Indian forests and species of conservation importance. The vital information generated on ecodistribution, variation in altitudinal gradient, forest types and KGCC maps determining habitat suitability and important climate types in the context of 50 prioritized FGR species of the Himalayan State have global significance and relevance specific to the Indian Himalayan Region (IHR), efforts by the UNCBD, UNFCCC, IUCN, ICIMOD, etc. Varied outputs also help in characterization of prominent and determinant environmental variables so as to develop understanding on the species suitability in a region.

The RS-based technology has provided an opportunity to gather data about the earth surface without physical contact and generating ecogeographic maps for 50 prioritized species. Although, a significant progress has been made in the development of SDMs and their use to study species distribution and characterize environmental niche, there is an ample scope for advancement and development so as to enhance the relevance and reliability of SDMs in the fields of forestry research and conservation, and addressing wider global environmental and societal challenges. Certainly, the MaxEnt Model is user friendly and allows non-GIS background researchers to develop required competence with little effort.

5.9.4.

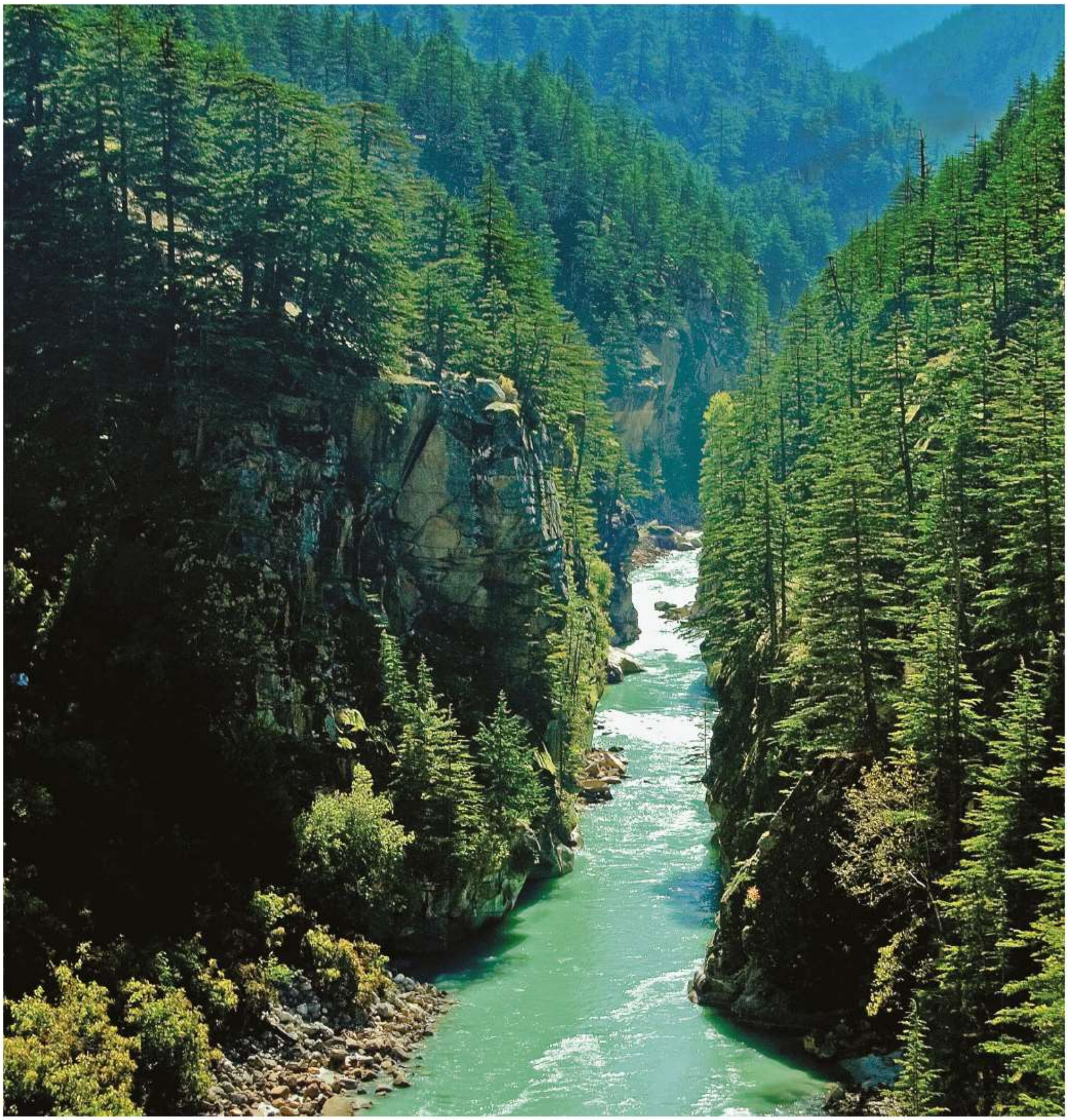
Recommendations and Priority actions

Ecogeographic maps of 37 species along with details on statistics have clearly shown their distribution range and provided an insight on other important bioclimatic variables and other aspects governing the distribution. Species with patchy and limited distribution range < 150 km^2 require utmost attention from the conservation perspective. The concerned DCF/ DFO needs to appreciate the risk faced by species having patchy or scattered distribution that too with small extent and incorporate appropriate management strategies in the respective Forest Working Plan. Further, 13 species having highly restricted and localized distribution with very small extent will need extra care for their management. Ecogeographic distribution map-based species-specific information needs to be corroborated with the corresponding data on their regeneration status provided in Chapter 3. Moreover, considering findings of the present study and in view of the threat perception to the prioritized FGR species, specific studies on highlighted priority research themes as described in Table 5.7 and periodic monitoring of these species with regard to their distribution, population size and regeneration status is recommended.

Sr. No.	Suggested Research Themes	Prioritized FGR Species
1.	Global Warming and Climate Change	*Abies spectabilis, Betula utilis, Tsuga dumosa, Quercus glauca*, and *Quercus lanata*
2.	Altitudinal/ Habitat Shift, and Seed Behaviour	*Quercus semecarpifolia, Carallia brachiata, Pittosporum napaulense, Premna mollissima, Pterospermum acerifolium, Trema orientalis, Carpinus viminea, Rhododendron arboreum, Acer ceasium, Buxus wallichiana*, and *Cornus capitata*.
3.	Forest Fire	*Myrica esculenta, Taxus wallichiana, Quercus glauca*, and *Quercus lanata*
4.	Anthropological Pressure	*Myrica esculenta, Betula utilis, Taxus wallichiana, Terminalia chebula, Cinnamomum tamala, Quercus semecarpifolia*, and *Quercus glauca*
5.	Phenology, Reproductive Biology, and Pollination	*Bombax ceiba, Phanera retusa, Buchanania cochinchinensis, Hymenodictyon orixense, Populus ciliata*, and *Ficus neriifolia*
6.	Forecasting Species Occurrence	*Machilus gamblei* and *Elaeodendron glaucum*
7.	Male and Female Sex Ratio, Ecological Population Structuring, and Sex Determination	*Betula utilis, Myrica esculenta*, and *Taxus wallichiana*

Table 5.7 Suggested Priority Research on Prioritized FGR Species based on Ecogeographic Mapping and Threat Perception

Sr. No.	Suggested Research Themes	Prioritized FGR Species
8.	Silvicultural Aspects	*Madhuca longifolia, Alnus nepalensis, Albizia julibrissin,* and *Juglans regia*
9.	Phytochemical Constituents and Medicinal Importance	*Cochlospermum religiosum, Diploknema butyracea, Litsaea glutinosa, Terminalia chebula, Semecarpus anacardium, Stereospermum chelonoides, Cinnamomum tamala, Corylus jacquemontii, Prunus cerasoides, Olea europaea* subsp. *cuspidata, Taxus wallichiana,* and *Juglans regia*
10.	Conservation Programs	*Albizia odoratissima, Boswellia serrata, Diospyros montana, Oroxylum indicum, Ougeinia oojeinensis, Hovenia dulcis, Fraxinus micrantha, Ulmus wallichiana, Betula utilis, Taxus wallichiana, Juniperus polycarpos, Flacourtia jangomas,* and *Cinnamomum tamala*



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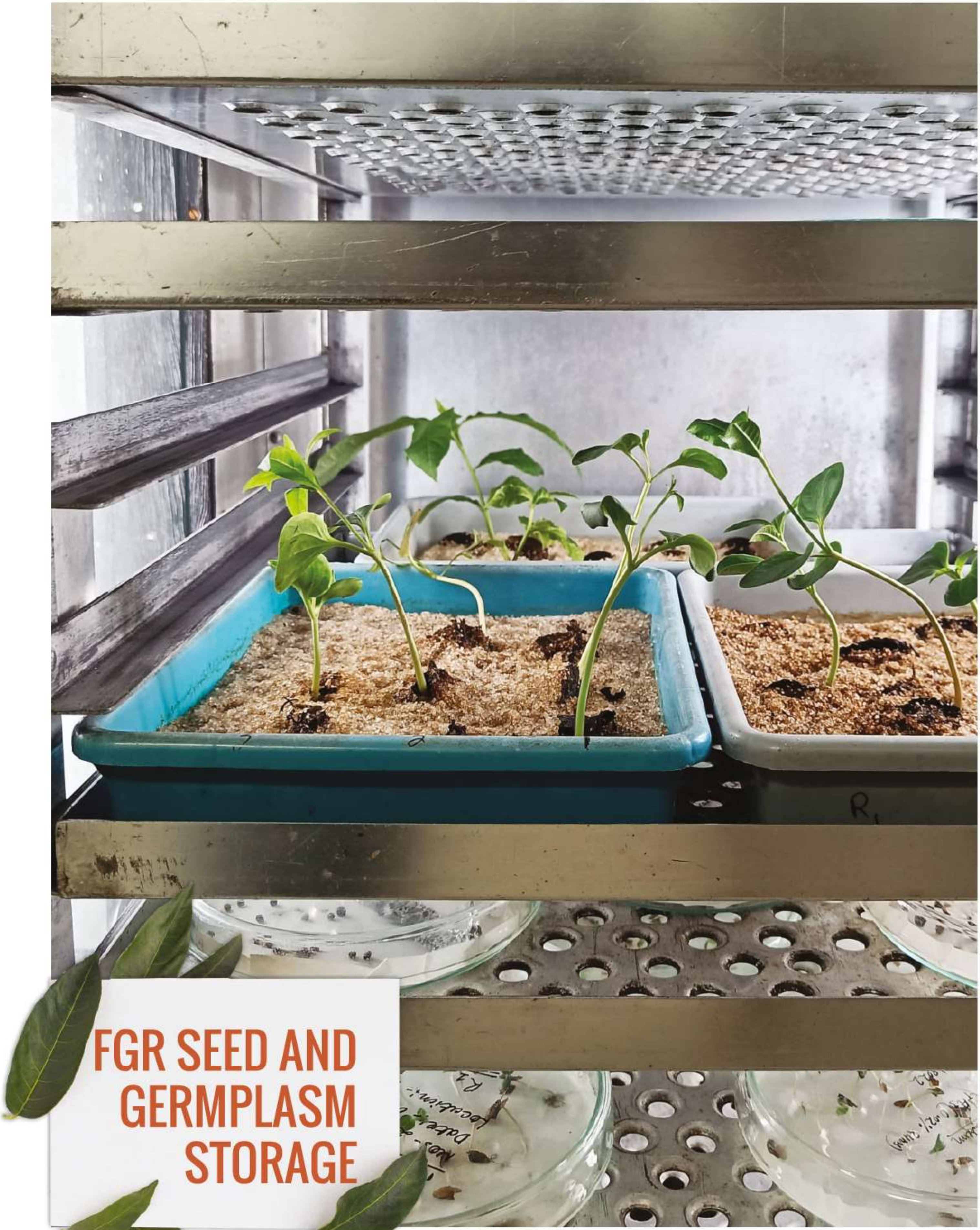
PART 03

GERMPLASM STORAGE AND *IN VITRO* CONSERVATION OF FGR

Plant germplasm broadly refers to the hereditary material (total content of genes) transmitted to the subsequent generations through germ cells. Seeds, pollens, plants, plant parts, or cultures are germplasm, useful in plant breeding, research, and conservation efforts or accessing the genetic information they possess for biotechnological applications. Storage and conservation of germplasm are of utmost importance for the maintenance of present diversity of forests. This part deals with the following three Chapters covering aspects of seed storage, in vitro pollen storage, and tissue culture protocols for RET and other FGR species.



FGR SEED AND GERMPLASM STORAGE

06

Thapliyal, M., Namitha, N.K., Rawat. P., Dangwal. S., Rathore. K., Kumar. A. and Rana. A.

FGR comprising trees, shrubs, and woody climbers are perennial, often long-lived plant species. The life span of FGR species, trees in particular generally ranges from about 10 to 15 years in case of short-lived pioneer species to 200 to 300 years for most larger species, and those found in arid zones. Trees include biggest and tallest organisms on the living planet. Most tree species reproduce sexually, although many have a combination of sexual and asexual reproductive means, while a few have lost the ability to reproduce sexually and are maintained as sterile, root suckering clones in certain parts of their range. It is possible that a long-distance seed or pollen dispersal may cause plants to regain a sexual mode of reproduction (FAO, 2014b). Long-lived FGR species at a particular site not only face extremes of environmental conditions, but also have some inherent adaptive capacity to withstand a wide range of human induced disturbances. Thus, they need to be able to endure environmental extremes and changes and/ or to persist in the soil seed bank or regrow from root suckers and coppice. The long-lived FGR species owing to their wider distribution and with adaptive and evolutionary potential under the environmental extremes exhibit high genetic diversity that characterizes tree populations and individuals with stress tolerance, and pest and pathogen resistance mechanisms, ultimately helping them to persist and thrive for longer periods.

Of all the life forms, FGR species, trees in particular require special attention for conservation as despite they offer a wide range of ecosystem services, face high level of extinction threat. As stated earlier, globally, forest ecosystems suffer on various accounts and FGR species are depleting. The maintenance of wilderness and natural forest ecosystems is a daunting task. Moreover, FGR species due to their actual and potential values are being increasingly used in tree improvement programs besides in afforestation, reforestation, ecorestoration, agroforestry, silvi-pastoral initiatives, and raising widespread commercial plantation of cash crops. Worldwide, humans have thus, transported and used seeds, nursery plants, vegetative propagules, and other germplasm extensively and intensively for such purposes in past two centuries or so. The conservation priority demands medium to long term storage of seed and other germplasm materials, especially in case of RET and other socio-economically important FGR species so as to safeguard such taxa in the face of any type of adversity, and to ensure their optimal use in programs related to tree improvement, enhancement of forest cover, fulfilling the ever-increasing requirements of timber and NTFPs, and biodiversity conservation.

6.1 Conservation of FGR Species

Germplasm provides the essential hereditary material to natural resource managers those are dealing with varied aspects of forest management, specifically raising nurseries, and plantations (afforestation, enrichment, avenue, commercial, etc.) besides tree improvement (NRC, 1991). Broadly, two approaches for germplasm conservation of FGR species are in practice (Wang *et al.*, 1993). Firstly, the *in situ* conservation wherein the germplasm is being conserved in its natural environment by establishing reserves, protected areas, etc. The approach is especially useful for conservation of FGR species in a near natural habitat along with several wild relatives so as to maintain high genetic diversity. However, the *in situ* conservation has some limitations on account of risk of losing germplasm owing to environmental hazards and human induced factors. Although, the cost of maintenance of a large number of genotypes as a wild gene pool is exorbitant and challenging in human dominated landscapes, but such efforts of *in situ* conservation immensely helps in the maintenance of species and genetic diversity, and ecosystem services. Secondly, the alternative approach of *ex situ* conservation is the prominent method for the storage of germplasm obtained from wild plant materials of FGR species. The genetic materials in the form of seeds or from in vitro cultures (plant cells, tissues or organs) can be stored for long-term as gene banks under suitable conditions. Germplasm resources are a strategic material essential to forest conservation, agriculture production, food security, and sustainable development as it is being increasingly used to develop new tree varieties of timber and NTFPs (seed, leaves, flowers, fruits, bark) for pulp, fodder, fiber, forestry, industrial, and medicinal purposes (NRC, 1991). .

6.2 *Ex situ* Storage of Seeds of FGR Species

Seeds are the most common and convenient materials, particularly for conservation of long-lived FGR species those produce a wide range of seeds varying in size, shape, nature of fruit, moisture content, etc., besides having some limitations due to their either seasonal availability or longer time gaps in seed production, small quantities, or even issues of viability (NRC, 1991). The objectives for seed storage are primarily either short term for forestry operations or long term for germplasm conservation. According to Bonner (1990), seeds can be broadly grouped into four classes of storage characteristics: (a) 'true orthodox' - seeds can be stored for longer periods at seed moisture content of 5 to 10 per cent and subfreezing temperatures; (b) 'sub orthodox' - seeds can be stored under the same conditions, but for shorter periods due to high lipid content or thin seedcoats; (c) 'temperate recalcitrant' - seeds cannot be dried at all, but can be stored for three to five years at near freezing temperatures; and (d) 'tropical recalcitrant' - seeds also cannot be dried, and they are killed by temperatures below 10-15 °C. In view of this, storage of seeds of FGR species for medium to long term periods is a challenge. In case of agriculture crop plants, production, transportation, and storage of seeds is not so difficult as they can be produced in a short span of time, in large quantities, and generally do not have limitations on account of their sensitivity to desiccation, long term storage and germination behaviour. Nevertheless, seed storage is the most widely accepted and adopted effective strategy towards long term *ex situ* conservation in case of most plant species. However, very little information on the seed biology (storage and germination) of tree and other FGR species in the context of Indian forests is available due to the vastness, high diversity, and limited resources (field collection, seed testing and viability, desiccation trials, storage, and manpower) for such purposes. It is essential prerequisite to demonstrate that seeds of tree and other FGR species can be stored for periods well in excess of the time to reach reproductive age and preferably the tree's lifespan (Pritchard *et al.*, 2014). Seed storage under control conditions is the most commonly used strategy for short (3-5 years) to medium (30 years or more) term *ex situ* conservation of forest trees (Wang *et al.*, 1993). Generally, this approach is applicable to compliment both the long term *in situ* conservation as well as *ex situ* methods (e.g., field gene banks, seed orchards). Primarily, this approach is being used in view of the practical difficulty of regenerating stored seeds of tree and other woody FGR species, especially when their germinability declines to below certain levels compared with agricultural crops. Bonner (1990) documented that the long-term seed storage for the equivalent of one rotation is possible for numerous woody species, and it could become a viable prospect for *ex situ* conservation. The objectives of seed storage in the context of conserving germplasms of FGR species is to maintain the initial genetic and physiological quality of the seeds until they are used or can be regenerated. This requires, adequate consideration and knowledge of prominent genetic and environmental factors affecting seeds of FGR species in storage. Further, the challenge remains to preserve the genetic diversity of a species or genetic stock for its use at anytime in future. This necessitates to understand the field level genotypic diversity in populations so as to plan the program of seed collection in order to acquire representative sets of samples of those populations/ species that merit conservation. In order to ensure a genetically diverse collection of seeds, adequate sampling from the distribution range of the selected species is of utmost importance for effective conservation. In case of several FGR species, germplasm may not be stored as seed. In such cases, germplasm needs to be maintained as live plants in the field or under cover (greenhouse or screenhouse), pollen, tissue cultures, or cuttings (NRC, 1991).

6.3

Planting Material in Tropical Countries

Seed is the primary source of planting material in tropical countries and the annual demand for forest tree seeds in India is about 10,000 metric tonnes. However, seed is often in short supply, of low quality and variable maturity and has limited storage life. Thus, there is an urgent need to establish the basic knowledge of seed collection, processing and seed storage physiology, etc. The desiccation-sensitivity and non-storability of many of the tropical forest tree seeds adds to these problems (Gunn, 1991). Seed storage is the most efficient and cost-effective means of *ex situ* plant germplasm conservation, and has been used to conserve a sizeable amount of plant biodiversity worldwide for decades (IBPGR, 1976). Seed storage behaviour refers to the capacity of seeds to survive desiccation. Desiccation tolerant or orthodox seeds can be dried, without damage, to low moisture content (mc). Seed longevity increases with reductions in mc and temperature in a quantifiable and predictable way. Desiccation sensitive or recalcitrant seeds do not survive drying to any large degree, and are thus not amenable to long- term storage, although the critical moisture level for survival varies among species. Intermediate seeds tolerate drying to around eight per cent mc and are a gradient from orthodox to recalcitrant, with no sharp boundaries between categories. They generally lose viability more rapidly at low temperature and do not withstand storage at -20°C.

Testing the viability of seeds before they are placed into storage, and also at regular intervals during the storage, is a key 'quality control' activity that gene banks are expected to do as a matter of routine (FAO, 2014a). Seed storage for long-term conservation involves desiccation of seeds to low moisture contents and storage at low temperatures (Hammer and Teklu, 2008). Techniques for conserving orthodox seeds have been perfected for several decades. These involve drying seeds to low moisture contents (3-7 per cent of fresh weight, depending on the species) and storing them in hermetically-sealed containers at low temperature, preferably -18°C or cooler. Desiccation tolerance protocols were developed by Hong and Ellis (1996), to determine seed storage behaviour based on drying seeds to two or three different moisture levels and assessing percentage germination.

About 80 per cent of FGRs of India are found in ten biogeographic zones in various forests in the country. Remaining 20 per cent of FGR are found in sacred grooves, pasture lands, community lands, agricultural lands, urban areas, botanical gardens, etc. As stated earlier, FGR species are facing several types of threats due to adverse abiotic and biotic stresses; habitat degradation, destruction, grazing, over-exploitation, forest fires, climate change and invasive alien species, etc., resulting in damage to forest ecosystem as well as loss of biodiversity. When genetic variation is lost through habitat destruction, succeeding generations are more exposed to adverse conditions such as atmospheric pollution, climate change, pests and diseases, etc. in addition, illegal trade of forest germplasm poses problem of losing valuable resources permanently. A long-term, multi-faceted approach of conservation of FGR has to be evolved and followed in the country. Both, *in situ* and *ex situ* conservation strategies as elaborated above are being followed in the country for FGR (Thapliyal and Namitha, 2017).

The high levels of genetic variation that are present within many tree species can be beneficially developed and used by foresters and tree growers. Accordingly, forestry and agroforestry production systems depend considerably on the continued availability of these diverse genetic resources at both the species and provenance (population) levels. The present Chapter specifically deals with the medium to long term storage of seeds of prioritized FGR species.

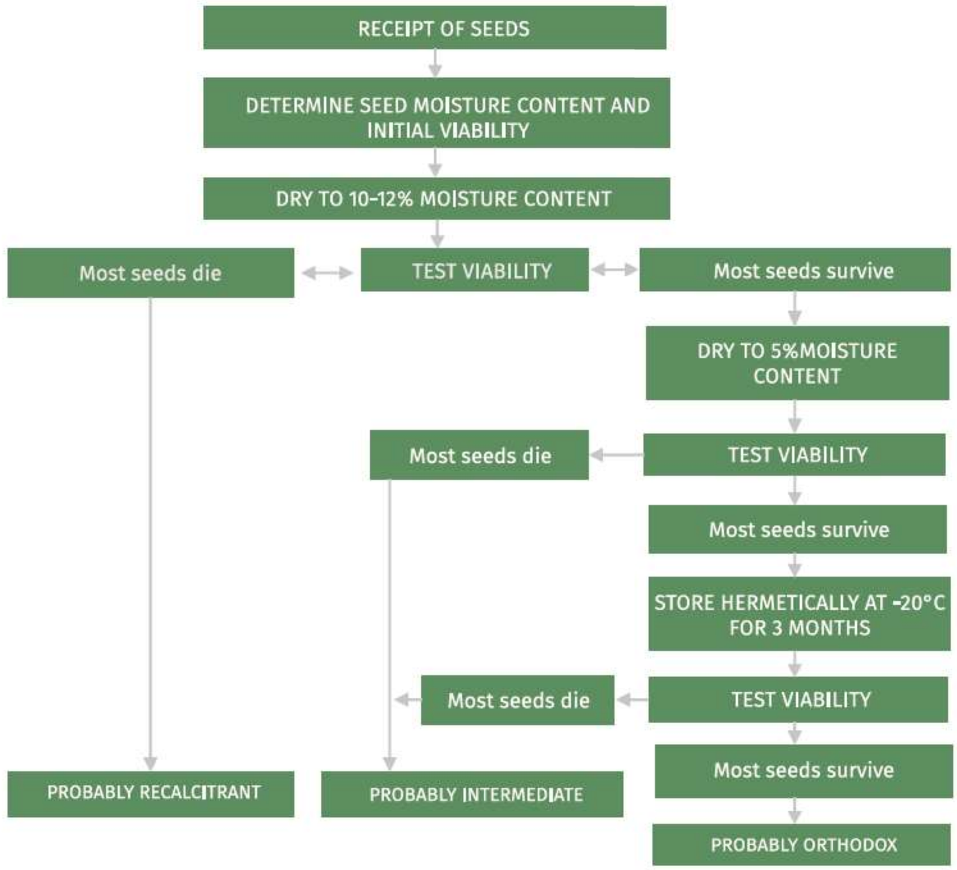


Fig. 6.1. Protocol to Determine Seed Storage Behaviour of Seeds

Source
Hong and Ellis (1996)

Conservation of Forest Genetic Resources

National Program for Conservation and Development of Forest Genetic Resources

6.4

Objectives

The Component on FGR Seed and Germplasm Storage under the Pilot Project envisaged developing medium- and long-term seed storage protocols for prioritized forestry species of Uttarakhand State. Following objectives were set forth for the present study dealing with the storage of seeds as germplasm of prioritized FGR species:

(i) Prioritize FGR species for medium- and long-term storage of seeds.

(ii) Undertake field level surveys for identification of varied populations for collection of seeds of prioritized FGR species.

(iii) Develop seed extraction, processing, quality testing methods for medium- and long-term seed storage protocols for prioritized forestry species.

(iv) Plan and collaborate for storage of desiccated seeds of selected FGR species, and ensure successful storage.

6.5

Materials and Methods

The process and approach adopted for prioritization of FGR species; population surveys; seed collection; seed extraction, testing, desiccation trials, and preparation for storage; medium to long term storage; and monitoring viability are described below one by one:

6.5.1

Prioritization of FGR Species for Medium- and Long-Term Storage of Seeds

A wider consultative process involving foresters, botanists, taxonomists and conservationists, following a broad criterion considering the socio-economic importance and ecological significance of forestry species was adopted for prioritization of 25 forest tree species of Uttarakhand State for the development of medium-term seed storage protocols. Thus, timber, fuelwood, fruit, fodder, and RET species besides species of ecological significance relevant to the current scenario were taken into account. Accordingly, 25 prioritized forestry species in the context of Uttarakhand State *viz.*, *Acacia catechu*, *Aegle marmelos*, *Albizia julibrissin*, *Berberis lycium*, *Bischofia javanica*, *Carpinus viminea*, *Celtis tetrandra*, *Dalbergia sissoo*, *Ougeinia oojeinensis*, *Fraxinus micrantha*, *Hippophae salicifolia*, *Holoptelea integrifolia*, *Juglans regia*, *Kydia calycina*, *Myrica esculenta*, *Oroxylum indicum*, *Picea smithiana*, *Pinus wallichiana*, *Punica granatum*, *Pyrus pashia*, *Rhamnus triquetra*, *Rhus parviflora*, *Toona ciliata* and *Rhododendron arboreum* were selected for the purpose of development of medium term seed storage protocols.

In addition, 100 FGR species were prioritized for the development of protocols for long term seed storage of seed samples in the seedbank (Table 6.1).

Table 6.1 Prioritized 100 FGR Species Selected for the Development of Long-Term Seed Storage Protocol and Storage in the Seedbank

Sr. No.	Species	Family	Location
1.	*Acer caesium*	Aceraceae	Bajrikhand, Kanasar Range, Chakrata FD
2.	*Abies pindrow*	Pinaceae	Chakrata FD
3.	*Acacia catechu*	Mimosaceae	Kalsi FD
4.	*Acer oblongum*	Aceraceae	Dehradun FD
5.	*Acronychia pedunculata*	Rutaceae	Nakraunda Forest
6.	*Aegle marmelos*	Rutaceae	Kansro, Rajaji National Park; Chhakata Range, Haldwani; Srinagar, Garhwal
7.	*Ailanthus excelsa*	Simaroubaceae	Sirsoli, Ukhimath, Kedarnath FD
8.	*Albizia chinensis*	Mimosaceae	Sahiya, Chakrata FD
9.	*Albizia julibrissin*	Mimosaceae	Arakot, Chamba
10.	*Albizia lebbeck*	Mimosaceae	Dehradun FD
11.	*Albizia odoratissima*	Mimosaceae	Rajpur Road, Mussoorie FD
12.	*Albizia procera*	Mimosaceae	Raiwala, Rajaji National Park
13.	*Alnus nepalensis*	Cupuliferae	Khirsu, Civil Soyam, Garhwal FD, Srinagar
14.	*Alnus nitida*	Cupuliferae	Tiuni, Kotigarh range, Tons FD
15.	*Bauhinia purpurea*	Caesalpinaceae	Dogri range, Haldwani FD
16.	*Bauhinia retusa*	Caesalpinaceae	Dugra Forest, Bhatwara, Tehri FD
17.	*Bauhinia vahlii*	Caesalpinaceae	Kilmori Forest, Bhatwara, Tehri FD
18.	*Bauhinia variegata*	Caesalpinaceae	FRI Campus, Dehradun
19.	*Berberis asiatica*	Berberidaceae	Garhwal FD
20.	*Berberis lycium*	Berberidaceae	Tiuni, Devdhar Range, Chakrata FD
21.	*Betula utilis*	Betulaceae	Mana, Badrinath FD
22.	*Bischofia javanica*	Euphorbiaceae	Jauljivi, Pithoragarh FD
23.	*Bixa orellana*	Bixaceae	Sushila Tiwari Herbal Garden, Rishikesh
24.	*Bombax ceiba*	Bombacaceae	Ratal, Tehri FD
25.	*Boswellia serrata*	Burseraceae	Near Chandi Devi Temple, Rajaji NP
26.	*Buchanania cochinchinensis*	Anacardiaceae	Near Chandi Devi Temple, Rajaji NP
27.	*Buxus wallichiana*	Buxaceae	Mandal, Kedarnath WLS; Jadi, Chakrata FD