Table 12.21
Effect of Different Methods of Air Layering and IBA Concentrations on Vegetative Propagation Success in *Diploknema butyracea*

Layering Technique	Rooting (%)	Survival (%)	Mean Root Length (mm)
FRI-wire technique without IBA	18.33	13.33	4.21
FRI-wire technique with 2,000 ppm IBA	48.33	38.33	4.54
Conventional air layering without IBA	15.00	10.00	4.38
Conventional air layering with 2,000 ppm IBA	33.33	28.33	4.67
$CD_{0.05}$	4.64	6.81	Not significant

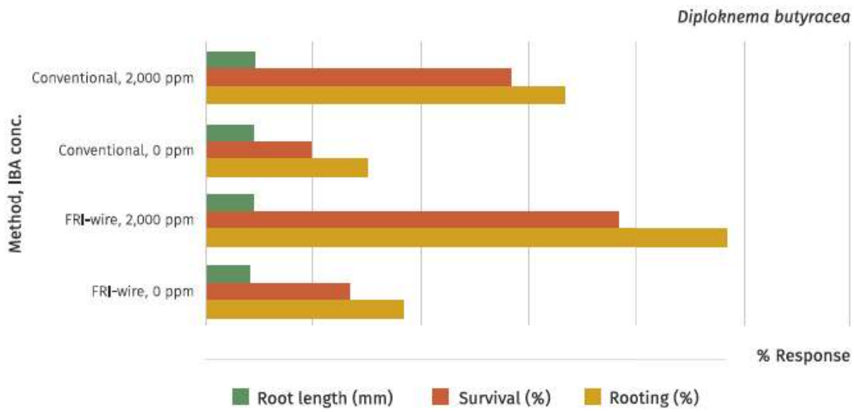

Fig. 12.17
Response of *Diploknema butyracea* to Different Air Layering Methods and IBA Concentrations

Conservation of Forest Genetic Resources

National Program for Conservation and Development of Forest Genetic Resources

Pilot Project

12.10 Production of Starting Material of Important Tree Species

Keeping in view the importance of the improved planting material for productive and protective functions/ conservation requirements, protocols, and capacities were developed for the propagation of the starting material for the commercial cultivation of economically important tree species, and also for the conservation of the remnant populations of the RET species. Species which were investigated are listed in Table 12.22.

Table 12.22
Starting Material Produced of Important Tree Species

Sr. No.	Species	Description of the Planting Material
1.	*Diploknema butyracea*	Also called as the Indian butter tree, one of the important NTFP species and is in threatened category. The population of this species in the State is almost localized in Pithoragarh district, particularly the areas bordering Nepal and adjoining areas of Almora, Bageshwar, and Champawat. In order to propagate and conserve this species, propagation protocols were developed and the promising material of four sources *viz.*, Champawat; Pithoragarh; FRI, Dehra Dun; and Almora were collected, multiplied and established in the form of field gene bank at Kali Kumaoun Range, Champawat Forest Division, Uttarakhand. Plants were also raised and supplied to other users (Fig. 12.19).
2.	*Rhododendron arboreum*	The State tree of Uttarakhand, *R. arboreum* has a great role in ecological stability of ecosystems, as indicators of forest health, and for their phenological sensitivity to climatic change. Over past few decades, natural populations have declined worldwide due to natural and anthropogenic pressures. Propagation protocols were developed for this species and the promising material of four sources *viz.*, Pauri, Tehri, Uttarkashi, and Chakrata (Kalsi) forest areas were multiplied and established in the form of field gene bank at Sandev Forest Range, Champawat FD. This will act as ex situ repository of the remnant populations and source of the diverse germplasm for propagation.
3.	*Myrica esculenta*	The State fruit of Uttarakhand, *M. esculenta*, is valued for its edible fruits and other by-products. This species has a potential income generating source for the local tribes of the Meghalaya,

Sr. No.	Species	Description of the Planting Material
		and the sub-Himalayan region. The demand of this species has led to illicit harvesting for the horticultural trade and habitat loss, pushing the plant to the brink of extinction. The nursery technique and propagation protocol of this species were developed and the material from the diverse sources *viz.*, Pithoragarh, Champawat, and Pauri were collected and propagated. The diverse germplasm was established in the form of field gene bank at Bhowali Forest Range, Nainital FD.
4.	*Cinnamomum tamala*	A valued medicinal plant and widely used as spice throughout the world since ancient times is known as tejpat/ bay leaves in trade, found in the Himalayan region. Owing to its high medicinal value, the demand of *C. tamala* is increasing day by day. Therefore, species has been recommended for *in situ* as well as *ex situ* conservation with devising appropriate management plans. The diverse germplasms of this species were collected from various sources of the State *viz.*, Nainital, Pauri, Pithoragarh, and Tehri. The material was propagated and the starting material was established in the form of *ex situ* repository at Nalena-II Forest Range, Nainital FD.
5.	*Taxus wallichiana*	Himalayan Yew is in high demand due to the presence of taxol in its bark, needles, and seeds. This metabolite is used for the treatment of breast and ovarian cancer. Due to illegal cutting of plant parts and other anthropogenic pressures, the species is endangered, and threatened with extinction, in the Himalayas. As the species grows slowly and regenerates poorly, vegetative propagation of its available germplasm is required for its *ex situ* conservation. The diverse germplasm of this species was collected from various sources within the State *viz.*, Chakrata (Kalsi), Chamoli, Uttarkashi, and Auli. The material was propagated and the starting material was established in the form of *ex situ* repository at Malari Beat, Joshimath Forest Range, Nanda Devi National Park.
6.	*Toona ciliata*	A multipurpose tree species, potentially valuable for agroforestry. Germplasm of selected 23 progenies from its natural range of distribution was established in the form of progeny trial cum germplasm bank at Village/ range Maikhura, Karanprayag FD. The starting material was propagated for its distribution to the users.
7.	*Dalbergia sissoo*	One of the premier timber species of India, commercially cultivated by farmers, SFDs, national highway authorities, and industries. Since few decades, severe mortality was noticed in the northern India that has been associated with various biotic and abiotic causes. Selected superior germplasm available with FRI, Dehra Dun was multiplied for screening to Fusarium wilt. In total, about 4,000 ramets were produced for 70 selected genotypes using mist chamber. The material was further maintained in the nursery. In addition, about 80 new CPTs were also selected from the distribution range, and seedlings are maintained in the nursery. The material will be further used for field evaluation, disease screening in other projects, and distribution to the growers.
8.	*Chukrasia tabularis*	A valuable multipurpose timber tree species, distributed in South and Southeast Asia. Planting material of selected 40 phenotypically superior trees was propagated in the nursery. The material will act as a starting material for establishment of field trials and distribution to users.
9.	*Ailanthus excelsa*	A fast-growing multipurpose agroforestry tree species. Planting material of 20 superior trees was multiplied as starting material for supply to other research projects and establishment of field trials. Material was distributed to Uttarakhand Forest Department.
10.	*Terminalia arjuna*	Important medicinal tree species, distributed all across India. Diverse seed sources collected from U.P., Haryana, Punjab, and Himachal Pradesh and propagated for the establishment of field gene banks and *ex situ* conservation reserves.

Sr. No.	Species	Description of the Planting Material
11.	*Bauhinia purpurea*	A multipurpose and moderately fast-growing tree species found in sub-tropical and tropical parts of India. It provides nutritious fodder and fixes atmospheric nitrogen in the soil. It has adaptability to grow up to 1,600 m altitude. Plant material from the lower Himalayas was multiplied in the nursery through seeds and the planting material was distributed to farmers and other tree growers.
12.	*Celtis australis*	A multipurpose tree species distributed in the lower and mid-Himalayan Ranges in Uttarakhand and Himachal Pradesh. Plant material was propagated in the nursery through seeds and the planting material was distributed to users.
13.	*Grewia optiva*	One of the most preferred fodder trees in the lower and middle Himalayas which is commonly grown by farmers in their private lands and community lands. It provides fodder when most of the fodder species in the villages are leafless. The bark yields fibre. Seeds were collected from phenotypically superior trees and plants were raised in the nursery. Plants were distributed to the users.

12.11

Discussion

12.11.1

Taxus wallichiana

12.11.1.1

Propagation Through Seeds

Seed germination is a critical phenomenon in *T. wallichiana* due to a long phase of dormancy (1.5 to 2 years) (Nandi *et al.*, 1997). The data revealed that varied source of populations and different concentrations of GA_3 did not have any significant influence on seedling survival (Table 12.2). However, seedling emergence increased as seed storage duration increased. Seedling emergence was not observed till 12 months of seed storage, beyond that seedling emergence was recorded in small numbers. When averaged across source populations, the highest seedling survival was 1 per cent achieved with 400 ppm GA_3 treatment of 42-month stored seeds, while 0.84 per cent seedling survival was noticed without the application of GA_3 in seeds stored for an equal length of time. Seeds of Chakrata and Kaddukhal populations stored for 42 months upon treatment with 400 ppm GA_3 recorded 1.33 per cent seedling survival while other populations registered 0.67 to 1 per cent seedling survival.

The present study carried out with seeds from different source populations within the State under the Pilot Project revealed that seedling emergence failed to occur when seeds stored for one year or less were sown. Soaking of seeds in GA_3 also failed to induce seedling emergence irrespective of duration of seed storage. The seeds were viable but did not germinate. Literature suggests that *Taxus* embryo is still immature, when the seeds are fully developed (Thomas and Polwart, 2003; Pullaiaha *et al.*, 2022). Le Page-Degivry and Garello (1973) working with *T. wallichiana* cultivar 'Fastigiata', found that embryo dormancy was removed when the seeds were cultured *in vitro*. Seedling emergence occurred when water-soluble leachates were removed by adding sucrose to the liquid nutrient medium. Tafreshi *et al.* (2011) carried out embryo culture to achieve rapid seedling emergence of *T. wallichiana* in the laboratory. Therefore, poor seedling emergence was attributed to immaturity of embryo.

All the sampled populations yielded very poor seedling emergence and survival even when the seeds were stored for 42 months. This suggests that use of seeds for raising nursery stock is an unreliable option in the species.

Fig. 12.18 Starting Material of *Diploknema butyracea* Raised for Distribution to Users

12.11.1.2

Propagation through Cuttings

To overcome the problem in propagation through seed, use of branch cuttings was explored. Scientific studies have been conducted in the past where *T. wallichiana* has been propagated by branch cuttings. Regardless of season, rooting was influenced by growth stage, IBA treatment and their interaction (Das and Jha, 2018a). Therefore, it is necessary to investigate the effect of maturity stage and IBA concentration. Sobha and Chauhan (2018) reported highest survival (58.25 per cent) with use of 500 ppm IBA. Treatment of cuttings with 100 ppm NAA gave 51.50 per cent survival. Plant age is known to influence rooting ability of trees; cuttings lose rooting ability as tree age. Osterc (2009) stated that root development in juvenile stock plant is high due to a higher endogenous auxin level. Trees of *T. wallichiana* are found in uneven aged natural stands and it is difficult to determine the age of trees. Age is indirectly related to stem diameter. Therefore, cuttings from trees of different diameters were collected and tested for rooting ability. Cuttings of 5 to 10 cm dbh and 10 to 15 cm dbh trees of *T. wallichiana* yielded 75.00 and 73.33 per cent rooting, respectively, while plants of 15 to 25 cm diameter recorded 35 to 55 per cent rooting (Table 12.3). The rooting success obtained from juvenile cuttings in the present study was higher than that reported by Sobha and Chauhan (2018). This might be due to the fact that Sobha and Chauhan (2018) used cuttings from mature trees.

Cuttings planted in gravel showed slightly higher rooting percentage than those in sand and vermiculite (Table 12.4). The species prefers to grow in moist, well-drained sandy soils (Taylor, 2014). Gravel matches the natural physical root environment of *T. wallichiana* better than vermiculite because gravel has better drainage than vermiculite. This could be a reason behind good rooting response of the species in gravel. Vermiculite is an expensive rooting medium as it is not locally found in the State. Gravel and sand are cheap and easily available at all places. Hence, use of gravel in preference to vermiculite has economic advantages. Das and Jha (2018b) tested six substrates i.e., field soil, forest soil, river sand, FYM, peat, and vermicompost for preparation of rooting media. Best root induction was recorded in forest soil + peat + FYM (1:1:1). Cuttings failed to root in sand. However, in the present study, rooting could be induced in sand using non-mist propagation chamber. Sand and vermiculite are frequently used in mist chambers in India. The success with gravel and sand suggests that these media can be utilised for planting cuttings of *T. wallichiana* in non-mist propagation chamber, thereby doing away with the need to procure vermiculite media for propagating this species.

The cuttings require humid environment for their developmental processes including sprouting, rooting, and growth. High humidity in the propagation environment reduces the rate of water loss, for this purpose they are conventionally planted in the mist chamber. Non-mist propagation chamber (Leaky *et al.*, 1990) is a low-cost propagation chamber that provides high humidity environment for growing cuttings and has been successfully used in FRI, Dehra Dun for propagating *Paulownia fortunei* (Kumar, 2007; Zargar and Kumar, 2018). The cuttings of *T. wallichiana* gave significantly better sprouting, rooting, and survival in non-mist propagation chamber than in the mist chamber (Table 12.4). This suggests that cuttings of the species can be planted in non-mist propagation chamber for propagation. Highest rooting and survival per cent of 76.67 was observed by planting cuttings in non-mist propagation chamber with application of 4,000 to 5,000 ppm IBA (Table 12.5). The high success rate found in the present study has not been earlier reported by the previous studies.

Non-mist chambers are very cheap, can be made locally, and do not require electricity for their operation. *T. wallichiana* occurs in forests in remote areas and high altitudes. Thus, use of the non-mist chamber would allow propagation of this important species in nurseries located in areas with little infrastructure near natural populations of *T. wallichiana*.

Khali and Sharma (2003) also reported IBA to be the most suitable hormone, followed by IAA and NAA for propagating the species through cuttings. This growth regulator led to greater rooting percentage, number of roots, and length of roots. Treatment with IBA at 10,000 ppm concentration was found optimum for root induction. In the present study, IBA was applied up to 5,000 ppm concentration and the higher concentrations generally effected greater root induction.

T. wallichiana is a dioecious species implying that male and female trees are different. Cuttings taken from male trees of the species were found to have higher sprouting, rooting, and survival percentage (Table 12.6). The survival after 5 months was 9 per cent higher taking success rate of cuttings from female plants as 100 per cent. In dioecious woody plants, females often make a greater reproductive effort than male individuals at the cost of lower growth rate. Robakowsky *et al.* (2018) hypothesized that female *T. wallichiana* individuals make greater reproductive effort than male; this might be associated with lower female photochemical capacity. It is hypothesized that a similar factor might be responsible for the lower rooting success of the cuttings of female plants. A practical implication of the finding is that 9 per cent more cuttings should be collected from female trees to produce as many plants as from male trees.

Rooting and survival of the cuttings of *T. wallichiana* were not found to significantly vary with the populations to which the cuttings belonged (Table 12.7). The best protocol for one population would obviously not be the best for another population, however, the protocol developed for one population would be successful in multiplying plants of other populations also. This implies that propagation protocol developed for one population can be used for propagating germplasm of other population too.

This is a significant finding of special interest to the plant propagators as they need not develop separate protocols for different populations.

12.11.1.3

Propagation through Air Layering

Air layering was found to be effective in vegetative multiplication of *T. wallichiana* (Table 12.8). IBA concentrations from 2,000 ppm to 5,000 ppm accelerated rooting and led to more than 60 per cent rooting while success was less than 12 per cent in the control. A large body of literature is available that recommends the use of IBA and other auxins during air layering for inducing roots in trees (Mishra *et al.*, 2002; Baghel *et. al.*, 2016; Purohit *et. al.*, 2016; Ahmad, 2021). Ishtiyak and Puni (2017) noticed a remarkable success in rooting *T. wallichiana* shoots of different diameters with application of IBA and IAA at 1,000 ppm and 2,500 ppm concentrations by employing FRI-wire technique of air layering.

From an overall assessment of results pertaining to *T. wallichiana*, it can be inferred that use of branch cuttings and air layering may be employed for vegetative propagation of the species with a high degree of success. Propagation through seeds is unreliable.

12.11.2

Rhododendron arboreum

12.11.2.1

Propagation through Seeds

Seedling emergence was satisfactory in the species. Highest value of seedling emergence being, 72.75 per cent was observed in seeds collected from Khirsu and treated with 300 ppm GA_3. Survival of seedlings was relatively low as it ranged from 8.50 to 24.75 per cent depending upon the population and GA_3 concentration (Table 12.9). It was, therefore, inferred that the species is not easily multiplied through seeds although seed germination is satisfactory.

Seeds collected from different populations yielded similar response from the standpoint of seedling emergence and seedling survival with 300 ppm GA_3 as well as control (Table 12.9). Even in 150 ppm GA_3 where differences in seedling emergence were significant, the range of variation was less than 15 per cent of the lowest value. Difference among populations were not found to be significant for survival. Thus, different populations behaved alike as far as propagation through seeds is concerned. In another study by Singh *et al.* (2021), seedling emergence was found to be low: a maximum of 39.57 per cent seedling emergence occurred at 29.00 per cent moisture content. Data on seedling emergence of ten species of *Rhododendron* in the Sikkim Himalayas revealed that seedling emergence is more dependent on species than on germination media (Singh *et al.*, 2008). Negi *et al.* (2019) found that sowing of seeds of the species in 150 ppm GA_3 solution for 12 h was the most effective treatment for improving the germination attributes with maximum germination of 87.33 per cent and germination capacity of 88 per cent, germination speed of 4.54, germination value 17.19, and germination index of 4.53. Thapliyal (2019) stated that no pre-sowing treatment is required for germinating the seeds of *R. arboreum*. Keeping in view the data on survival percentage, propagation through seeds does not appear to be a reliable method for propagating the species.

12.11.2.2

Propagation through Cuttings

Perusal of data in Table 12.10 revealed that branch cuttings of *R. arboreum* did not root well despite exogenous application of IBA. Rooting occurred on treatment with IBA but the rooting and survival percentages were very low. The branch cuttings, thus, proved hard to root and gave unsatisfactory results despite application of IBA. Reports are not available on success of cuttings in propagating the species implying low probability of success of propagating *R. arboreum* through branch cuttings.

However, use of root cuttings from the root suckers yielded some encouraging results (Table 12.11). The values of rooting and survival were in the range of 21.75 to 38.00 per cent and 6.50 to 27.25 per cent, respectively. Root cuttings can thus be used to multiply the species in the nursery with a moderate level of survival percentage.

12.11.2.3

Propagation through Air Layering

On perusing the data pertaining to effect of month, auxin type, and auxin concentration on air layering success in *R. arboreum* (Table 12.12), it was observed that May was the most favourable month for carrying out air layering, followed by April. March registered lowest success. IBA proved most effective, followed by IAA. Highest value of rooting being, 73.33 per cent was recorded with application of 4,000 ppm IBA. Ahmad *et al.* (2021) attempted air layering in the species using FRI-wire technique during February and recorded maximum 61.11 per cent rooting with application of 2,500 IAA. The present study, thus, resulted in better success than that reported by Ahmad *et al.* (2021). Air-layering is performed best during spring and summer (Hartmann *et al.*, 2010). It might be due to a combination of several factors namely month, type of auxin, concentration of auxin, difference in environment, and other factors. July (rainy season) proved to be better season for making air layers than October (post-rainy), January (winter), and March (spring) in Spondias pinnata in Prayagraj. Among three concentrations of 100, 300, and 500 ppm of IAA and IBA, the highest i.e., 500 ppm concentration proved most effective (Tomar, 2016).

On conducting air layering on trees of *R. arboreum* in three populations in the State in the present study, significant differences were observed in success rates among the various locations with 4,000 ppm IBA (Table 12.13). Variation in rooting among the locations was not significant at 2,000 ppm IBA. However, it can be judged that 4,000 ppm and 2,000 ppm evoked rooting in all the three populations; the differences among the populations were in degree of success. The 4,000 ppm concentration gave greater positive response than 2,000 ppm. IBA at 4,000 ppm concentration can thus, be safely applied during air layering, irrespective of the population to induce rooting.

Therefore, propagation through seed and air layering were found to be satisfactory methods for propagation of *R. arboreum*.

12.11.3

Myrica esculenta

12.11.3.1

Propagation through Seeds

Scarification was found to be effective in overcoming dormancy and germinating the seeds of *M. esculenta*. Treatment of seeds with concentrated H_2SO_4 for two minutes resulted in 40 per cent seedling emergence (Table 12.14). Rawat *et al.* (2012) pre-treated seeds of this species with mechanical scarification by slicing off the end of the seed, soaking in sulphuric acid for 4, 8, and 12 minutes, and soaking in hot water for 24, 48, and 72 h. Seeds of some scarification methods were also treated with GA_3 at 50 and 100 ppm concentrations. All pre-treatments improved the seedling emergence from seeds, the highest being mechanical scarification with soaking in 100 ppm GA_3 (85.00 per cent); next highest seedling emergence was with the sulphuric acid and hot water soaking treatments. The maximum survival (60.00 per cent) of seedling was achieved with 48 h hot water soaking. Treatment of *M. esculenta* seeds with sulphuric acid for 5 minutes enhanced seedling emergence to 32.92 per cent from 24.30 per cent observed in the control (Bhatt *et al.*, 2000). On the contrary, Shah and Tiwari (2010) observed that seeds of the species treated with different concentrations and durations of sulphuric acid (H_2SO_4) failed to germinate. Seeds treated with hot water gave the highest seedling emergence ranging between 33 and 57 per cent.

In view of contrasting findings, treatment of seeds with sulphuric acid may be considered a relatively unreliable method for germinating seeds of the species.

12.11.3.2

Propagation through Cuttings

Branch cuttings of *M. esculenta* were subjected to various auxin and supplement treatments. Rooting was low, the highest being 18.33 with 13.33 per cent survival obtained on treatment of cuttings with NAA 2,000 ppm + 5 per cent Captan + 5 per cent Sucrose (Table 12.15). Chaukiyal (2015) could obtain negligible rooting in the species by applying 4,000 ppm IBA, nonetheless, all the cuttings died.

12.11.3.3

Propagation through Air Layering

Chaukiyal (2015) reported maximum 15.83 per cent rooting when air layering was performed with 4,000 ppm IBA concentration. Air layering was attempted during two years in the present study but rooting was not achieved as the plants were damaged by humans and monkeys.

From the above results, it is seen that propagation of *M. esculenta* presents difficulty. Success with seed, cuttings, and air layering was quite low and results are relatively unreliable. There is a need to carry out further research on propagation of the species.

12.11.4

Cinnamomum tamala

12.11.4.1

Propagation through Seeds

Seeds depulped before sowing resulted in greater seedling emergence and survival in comparison with control (Table 12.16). Depulping of seeds with hand or cow dung proved better (74.44 to 78.33 per cent seedling emergence and 67.22 to 68.89 per cent survival) than depulping by soaking in water. Kuniyal *et al.* (2013) did not observe germination in seeds with pulp. However, depulped seeds recorded 75.56 per cent seedling emergence. In another study in the natural environment on forest floor, depulped seeds exhibited more seedling emergence (74 per cent) than seeds with intact pulp (56 per cent). Seedling emergence is greatly influenced by the natural environment.

Depulped seeds recorded highest seedling emergence in undisturbed close canopy forest (92 to 98 per cent), followed by disturbed forest irrespective of canopy closure (>75 per cent) (Sharma *et al.*, 2009).

Sowing of seeds at 3 cm depth in an upright condition led to better seedling emergence than sowing at 5 to 7 cm depth or in horizontal or inverted orientation (Singh *et al.*, 2017). Bhatt *et al.* (2007) successfully propagated the species through seed.

12.11.4.2

Propagation through Cuttings

Cuttings of *C. tamala* sprouted but failed to root without application of IBA (Table 12.17). IBA concentrations of 3,000 to 5,000 ppm were more effective than control or 2,000 ppm in root induction and plant production. Treatment of cuttings with 5,000 ppm IBA resulted in greatest rooting and survival (32 and 26 per cent, respectively) of cuttings. The source of populations in case of cuttings had negligible effect on rooting and survival (Table 12.18). Greatest survival (21.67 per cent) was observed in cuttings collected from Bhowali (Nainital) and subjected to 4,000 ppm IBA.

In a study on *C. verum*, application of IBA or IAA at 2,000 ppm concentration was effective for rooting of terminal shoots with 73 and 65 per cent success, respectively (Rema and Krishnamoorthy, 1993). Softwood cuttings of *C. zeylanicum* treated with NAA 5,000 ppm resulted in 22.5 per cent rooting whereas hardwood cuttings treated with IBA 2,500 resulted in 45.0 per cent rooting (Vadivel *et al.*, 1981).

12.11.4.3

Propagation through Air Layering

Semi-hardwood shoot was found to be ideal for air layering in cinnamon (Rema and Krishnamoorthy, 1993; Ranaware *et al.*, 1994). Semi-hardwood shoot was, therefore, used for air layering. On perusing data on air layering experiment in *C. tamala*, May and July proved to be the most successful months for carrying out air layering process (Table 12.19). The mean rooting success was 54.07 to 56.30 per cent during this period. However, data on interaction effect revealed that air layering during July with 4,000 ppm IBA recorded the highest rooting per cent being, 86.67 which was closely followed by 82.22 per cent rooting recorded for air layering during May with 4,000 ppm IBA. Seasonal variation in rooting of air layers has also been documented earlier. About 88 per cent rooting was observed in July, followed by 65 per cent in June in Maharashtra with no rooting during January and February (Ranaware *et al.*, 1995). Application of 3,000 ppm IBA resulted in 70 per cent rooting in semi-hardwood cuttings of *C. zeylanicum* in Cochin (NRCS, 1990).

Therefore, from the above experiments, it was inferred that *C. tamala* could be multiplied through seeds and air layering with a high degree of success. Propagation through branch cuttings was relatively less reliable as survival was only 26 per cent despite application of 5,000 ppm IBA.

12.11.5

Diploknema butyracea

12.11.5.1

Propagation through Seeds

D. butyracea is very easily propagated through seed. Hence, detailed experiments on propagation technique were not conducted under the project. Plants raised from seeds recorded seedling emergence of 88 to 95 per cent and survival was 85 to 90 per cent.

12.11.5.2

Propagation through Cuttings

Juvenile cuttings recorded 63.90 per cent rooting against 4.20 per cent rooting in mature cuttings (Table 12.20). Mature cuttings failed to survive after planting in the field while survival of juvenile cuttings was 56.60 per cent. In a similar study on *D. butyracea* by Zargar and Kumar (2018), per cent rooting decreased as age of the donor plants increased. Maximum rooting of 66.70 per cent was observed in juvenile branch cuttings which decreased to 4.40 per cent in cuttings collected from mature donor plants. Juvenile branch cuttings showed high survival rate (87.80 per cent). Maturity stage had a significant effect on the mean number and mean length of roots per cutting.

Studies were earlier conducted at FRI, Dehra Dun by Zargar (2015) to determine suitable length and diameter of cuttings of *D. butyracea* for propagation. Branch cuttings of 1.5 to 2.5 cm diameter and 16-20 cm length gave the best rooting percentage of 71.20 per cent when taken from juvenile plants. It was also observed that branch cuttings could be planted during monsoon season (July) or during spring season (February). However, rooting percentage (53.90) and survival percentage (76.10) were higher in the monsoon season. Thus, propagation through seeds and juvenile cuttings proved as the most successful methods of propagation of *D. butyracea*.

12.11.5.3

Propagation through Air Layering

Air layering of juvenile plants is also effective while mature plants on air layering gave a moderate success of 38.33 per cent (Table 12.21). Application of 2000 ppm IBA was crucial to achieve greater root induction by FRI-wire technique as well as by conventional method of air layering.

It must be emphasised here that planting material derived through seeds is expected to have greater genetic diversity, hence plants from seeds may be preferred to vegetatively propagated plants, other things being equal, in gene banks and conservation areas to maintain greater genetic diversity. The plant material raised under the Pilot Project was utilized to raise field gene banks (Table 12.22).

12.12

Conclusion

Prominent research findings in case of five prioritized FGR species based on various propagation methods tried are summarized below:

Taxus wallichiana: Fresh seeds of *T. wallichiana* failed to germinate; the six studied populations in the State yielded very low (≤1.33 per cent) seedling survival with the best storage duration of 42 months. The use of seeds proved to be an unreliable option for raising nursery stock in the species. Branch cuttings of plants of 5 to 15 cm dbh led to 70 to 77 per cent survival which was significantly higher than the 42 per cent success with >15 dbh.

Branch cuttings of *T. wallichiana* planted in gravel showed higher rooting percentage than in sand or vermiculite. Better sprouting, rooting, and survival were obtained in non-mist propagation chamber than in the mist chamber. Highest value of rooting and survival being, 76.67 per cent was observed by planting cuttings in non-mist propagation chamber with application of 4,000 to 5,000 ppm IBA. The high success rate found in the present study has not been reported in earlier studies. Non-mist chambers are very cheap, can be made locally, and do not require electricity for their operation.

Branch cuttings taken from the male trees of *T. wallichiana* were found to have higher sprouting, rooting, and survival percentage than those from female trees. It was estimated that 9 per cent more cuttings should be collected from female trees to produce as many plants as from male trees. Air layering with application of 2,000 ppm to 5,000 ppm IBA accelerated rooting and led to more than 60 per cent rooting while success was less than 12 per cent in the control.

Rhododendron arboreum: *R. arboreum* could be easily germinated and different populations behaved alike showing increase in germination on treatment with 300 ppm GA_3, but seedling survival was low. Branch cuttings of *R. arboreum* proved hard to root and gave unsatisfactory results despite application of IBA. However, root cuttings proved a modest success in multiplying the species with 6.50 to 27.25 per cent survival. A maximum 73.33 per cent rooting was recorded during air layering in the species with application of 4,000 ppm IBA. It was further found that IBA at 4,000 ppm concentration can be safely applied during air layering, irrespective of the population, to induce rooting. When tested at three locations, the survival percentage of air layering was found to be 46.67 per cent.

Myrica esculenta: Treatment of *M. esculenta* seeds with concentrated H_2SO_4 for two minutes resulted in 40 per cent seedling emergence. However, in view of contrasting findings vis-à-vis past reports, treatment of seeds with sulphuric acid may be considered a relatively unreliable method for germinating seeds of the species. Rooting of *M. esculenta* branch cuttings was poor with a mere 13.33

per cent survival on treatment with NAA 2,000 ppm + 5 per cent Captan + 5 per cent Sucrose. Success was not achieved in air layering.

Cinnamomum tamala: In *C. tamala*, depulping of seeds with hand or cow dung improved germination response by about nine times yielding 74 to 78 per cent seedling emergence and 67 to 69 per cent survival. Branch cuttings of *C. tamala* failed to root without application of IBA. Greatest rooting and cutting survival (32 and 26 per cent, respectively) were achieved with 5,000 ppm IBA. The source of populations had negligible effect on rooting and survival of cuttings. Air layering in *C. tamala* during July with 4,000 ppm IBA recorded the highest value of rooting being, 86.67 per cent.

Diploknema butyracea: Propagation of *D. butyracea* through seeds proved very easy as they germinated readily and led to about 85 to 90 per cent seedling survival at the time of outplanting. Juvenile branch cuttings of *D. butyracea* gave a high survival of 60.83 per cent while 1.67 per cent survival was recorded for mature cuttings. FRI-wire technique of air layering coupled with 2,000 ppm IBA gave better results (38 per cent success) than the conventional technique (28 per cent) with equal dose of IBA in 8-year-old plants.

12.13

Recommendations

The recommendations about choice of the propagation methods and their success rates for the five species is presented in Table 12.23.

The species may be multiplied in the nursery using seeds, branch cuttings, root cuttings, or air layering. The plants thus raised may be planted in the field for carrying out afforestation, reforestation, enrichment planting, and for establishing gene banks or conservation areas. Private or community plantations may also be established using the plants. Differences in propagation success of a given species may vary with population being propagated, however, the variation is expected to be within a range of 10 to 15 per cent only. Non-mist propagation chambers are cheaper than mist chambers, however, they are also effective in providing suitable environment for vegetative multiplication of the tree species through cuttings.

Table 12.23 Recommendation About Propagation of Plants in Nursery, Based on Findings of Various Experiments

Sr. No.	Species	Recommended Method of Propagation of Plants and Success Rate (Plant Per Cent)
1.	*Taxus wallichiana*	Branch cuttings: 70 to 77 per cent survival, Air layering: 35 to 40 per cent survival
2.	*Rhododendron arboreum*	Air layering: 38 to 60 per cent survival, Seeds: 9 to 25 per cent survival Root cuttings: 7 to 27 per cent survival
3.	*Myrica esculenta*	Branch cuttings: 10 to 13 per cent survival, Seeds: 26 to 36 per cent survival
4.	*Cinnamomum tamala*	Seeds: 67 to 69 per cent survival, Air layering: 45 to 57 per cent survival
5.	*Diploknema butyracea*	Seeds: 85 to 90 per cent survival, Branch cuttings: 55 to 60 per cent survival

12.14

Key Messages

Five high priority species *viz., T. wallichiana, R. arboreum, M. esculenta, C. tamala* and *D. butyracea* were taken up for developing propagation protocols. The level of difficulty in propagation varied with the species. The success rate achieved during the project in multiplying *M. esculenta* has been relatively low. More studies need to be conducted on propagating the species. Other tree species in the State which have high conservation value but lack propagation protocols too deserve to be identified and studied in the future for developing nursery practices.

12.15

Priority Actions

The protocols developed for the five priority species *viz., T. wallichiana, R. arboreum, M. esculenta, C. tamala* and *D. butyracea* may be adopted for establishing field gene banks and plantations in the State. *T. wallichiana* is a dioecious species implying that male and female plants are separate, therefore, in case of *T. wallichiana* and other dioecious species, care should be taken to collect cuttings from trees of both the sexes. This consideration would also apply to air layering since both the techniques produce true-to-type plants. The rooting success of female plants of *T. wallichiana* was found to be nine per cent less than male plants, hence, additional cuttings of female plants may be planted at time of propagation in the nursery in order to ensure that female plants are not under-represented in the plantation. In order to undertake vegetative propagation through cuttings, non-mist propagation chambers may be installed in places where it is not possible to install the conventional mist chambers due to high cost involved in the latter. Planting material derived through seeds is expected to have greater genetic diversity, hence plants from seeds may be preferred to vegetatively propagated plants, other things being equal, in gene banks and conservation areas to maintain greater genetic diversity. Specific actionable points emerged from the present study are as follows:

(a) Raise plants of *T. wallichiana, R. arboreum, M. esculenta, C. tamala*, and *D. butyracea* in the nursery through the standardized and recommended protocols as above.

(b) Establish field gene banks and conservation areas using plants raised in the nursery while giving preference to plants produced through seeds.

(c) In case vegetative propagation is unavoidable, such as in *T. wallichiana* where seed availability and/ or seed germination are very low and trees are dioecious¸ care should be taken that the trees of both the sexes are propagated.

12.16

Future Prospects

Protocols have been developed for propagation of five priority species *viz., T. wallichiana, R. arboreum, M. esculenta, C. tamala* and *D. butyracea* in the nursery. Seeds of *T. wallichiana* are not easily available, hence branch cuttings and air layering procedure may be applied when large number of plants of the species are required to be planted. For the remaining species, seeds can be easily employed besides vegetative propagation methods. While carrying out vegetative propagation of dioecious species such as *T. wallichiana*, care should be taken to ensure that propagules are taken from trees of both sexes. Non-mist propagation chambers may be installed in places where it is not possible to install the conventional mist chambers due to high-cost concerns, for carrying out vegetative propagation through cuttings. Planting material from seeds is likely have greater genetic diversity than that from vegetative propagation, hence the former may be preferred for establishing gene banks and conservation areas.

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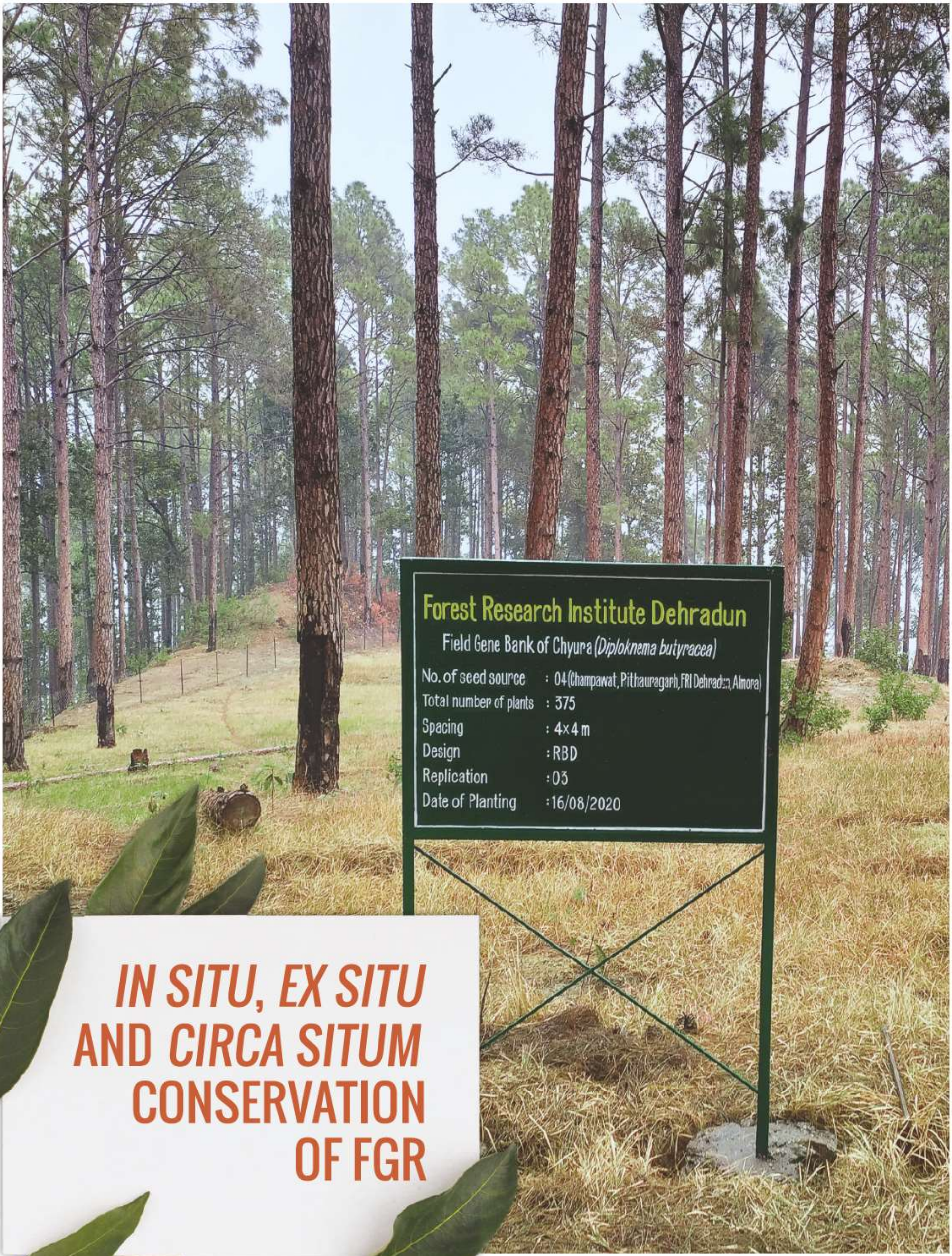

IN SITU, *EX SITU* AND *CIRCA SITUM* CONSERVATION OF FGR

13

Kant, R., Yadav, A. and Ginwal, H.S.

In India, conservation of forests and FGR is strongly allied with two broad types of concurrent conservation approaches (State driven and Community driven) towards protection of nature and biodiversity governance as continuum across landscapes, and have evolved over a long period of time. These approaches have already been elaborated (see section 1.10). Landscape level approach towards biodiversity conservation focusses on conserving the whole array of biological diversity *in situ*, from genes to organisms while allowing the ecological and evolutionary processes to be maintained. These processes, simultaneously help in maintaining and protecting the variability within forests, trees, shrubs, and other woody species within especially designed and set aside conserved areas. The maintenance of broader goals pertaining to genetic and species diversity in FGR conservation complements with the global agenda on habitat and ecosystem protection for biodiversity conservation. *In situ* conservation is often considered as the core activity of biodiversity conservation, and also in case of vast diversity of FGR as it not only allows the continuance of vital ecological processes and ecosystem services but also maintains the existing natural pool of genetic variability alongside permitting natural selection process to operate. *In situ* conservation has been recognized as the first key step in conservation of FGR and other forms of biodiversity. Alternative approach involving *ex situ* measures is generally considered when it is realized that *in situ* conservation is not feasible, or a species is at serious risk of extinction in the wild. The former approach of *in situ* conservation not only helps in the persistence of wider conservation significance values *viz.*, real, biological, ecological, conceptual, scientific, aesthetic, ethical and cultural at the same time, but also ensures that large amounts of FGR are also effectively conserved through simultaneous conservation of a huge diversity of multiple species. In contrast, *ex situ* conservation helps to preserve a 'snapshot' of the variability present at the time of conservation of germplasm.

FGR can be conserved *in situ* or *ex situ*, statically or dynamically. In this approach of conservation along two axes, former axis denotes the location of conservation i.e., the existing site of population (*in situ*) or in another location (*ex situ*), respectively, while the latter axis (static or dynamic) pertains to the objective of conservation (EUFORGEN, 2021). In case of static conservation, existing genetic diversity of the population is being conserved, while in dynamic type of conservation, the evolutionary potential of the population is allowed to be maintained. Increasingly, the worldwide emphasis of FGR conservation is on *in situ* approach with a dynamic orientation. The *ex situ* conservation of FGR focusses on static efforts that too away from the natural environment e.g., field gene banks. Complementarity between in situ and *ex situ* conservation approaches has been well recognized as a highly endangered population in a dynamic *in situ* condition will need back up of static *ex situ* conservation outside the species' natural range. Likewise, *ex situ* conservation measures firstly, may require periodic replenishment or supplementation of germplasm from the natural environment of the species and secondly, the stored germplasm may be used to rehabilitate the depleted populations in their natural habitats.

Further, in the context of human-modified tropical landscapes which represent a mosaic of natural, semi-natural and agroecosystems in close proximity to one another, it has been realized that *in situ* conservation areas, predominantly PAs, and rural agroecosystem based human modified landscapes cannot be seen as independent entities, but they are ecologically interacting components of a single large system (Terborgh *et al.*, 2002; Gardner *et al.*, 2007; Anand *et al.*, 2010). It is widely accepted that PAs are the building blocks for an effective way to conserve biodiversity, but by themselves they are inadequate to conserve tropical biodiversity in the long run as they are small in size, widely scattered, embedded in human dominated landscapes, and continue to face enormous challenges (Stolten and Dudley, 1999). Human modified landscapes in different parts of the tropical world including India typically feature greater habitat heterogeneity and structural complexity while retaining considerable native forest cover in the form of widely distributed forest patches comprising smaller extents of original large forest trees left in the clearings by traditional farmers; or planted and/ or remnant trees; or wildings in farm lands. These forest patches of planted trees and/ or remnant trees in agricultural landscapes where wild stands were once found have been recognized as *circa situm* reservoirs of biodiversity (Dawson *et al.*, 2009 and 2013). Studies suggest that loss of remnant forest patches or *circa situm* reservoirs from human modified landscapes is not only likely to reduce biodiversity within agroecosystems but also exacerbate overall biodiversity loss in such situations (Anand *et al.*, 2010).

13.1

In situ Conservation

'On site' or *in situ* conservation or 'nature conservation', as a movement is deep rooted to the time when it was evolved out of necessity to maintain vital natural resources as they were plundered to meet enhanced human and developmental demands. The preceding section 1.10 has highlighted that India's ethos and culture promotes conservation of nature which is deeply embedded in the multihued Indian society. Since time immemorial, the country has implemented a continuum of five biodiversity governance models across landscapes. The section 1.11.9.1. has already provided a detailed account on varied *in situ* approaches (sacred groves, protected areas, managed forests, tiger reserves, elephant reserves, biosphere reserves, and world heritage sites) besides preservation plots and plus trees, adequately supported by a number of policies, legislations, institutions, and mechanisms of governance and program implementation at multiple hierarchical levels.

13.1.1

Protected Areas

India has established a network of legally designated protected areas (national parks, wildlife sanctuaries, conservation reserves, and community reserves) under the provisions of Wildlife (Protection) Act, 1972, and following a basis of biogeographic classification. Presently, country has altogether 987 PAs covering a cumulative extent of 1,73,053.69 km^2 or 5.26 per cent of geographical area of the country. In most instances, managed forests comprising reserved forests, protected forests and unclassed forests, legally designated as per provisions of the Indian Forest Act, 1927 collectively cover yet another substantial extent of 6,02,234.31 km^2 and serve as buffer areas to PAs. These buffer areas serve twin goals of forest management *viz.*, sustainable production of forest products and services, and conservation of biodiversity besides promoting the agenda of 'co-existence' while allowing activities of different production sectors. These prominent *in situ* conservation efforts have allowed to maintain a spectacular and unique terrestrial floral and faunal diversity in forest ecosystems including carnivore species like tiger, Asiatic lion, snow leopard, clouded leopard, common leopard, and wild dog; mega herbivores - Asian elephant, and Greater one horned rhinoceros; and wide array of ungulates, primates, etc. besides a vast diversity of FGR species. Further, globally/ nationally initiated conservation programs like Biosphere Reserves, World Heritage Sites, Project Tiger, and Project Elephant are some of the important conservation efforts helping in sustenance of ecosystem services and maintenance of forest-based biodiversity.

13.1.2

In situ Conservation of Genetic Diversity

Although, above stated *in situ* approaches have made notable contributions towards the conservation of biodiversity, particularly forest diversity including FGR, and provide an insurance against catastrophic events. However, genetic diversity of populations *in situ* sites may erode over time, especially if the populations are small and fragmented or disjunct. Decline in genetic diversity in several tree and other FGR species whose populations are sparse or isolated with little or no gene flow among the population or patches has been reported (Doligez and Joly, 1997; Uma Shaanker *et al.*, 2002). Growing literature on molecular characterization and conservation of biodiversity provides two pointers: (a) intraspecific genetic diversity is key in providing populations with the capacity to adapt to the changing environmental conditions, and (b) the unprecedented rates of biodiversity loss raise the urgency for preserving species' ability to cope with ongoing global changes including challenges of higher loads from novel pests and pathogens (Zampiglia *et al.*, 2019; Minter *et al.*, 2021). Thus, it has been lately realized that conserving genetic diversity is of utmost importance for mitigating biodiversity loss and enabling species to respond to changing environments (Reed and Frankham, 2003; Wernberg *et al.*, 2018; Minter *et al.*, 2021). Maintenance of genetic diversity within tree and other FGR species and the processes that determine it are key for sustainable forest management and enhancing the resilience of diverse forests (Hubert and Cottrell, 2014).

At any given time, the genetic diversity within a tree species is the result of varied dynamic processes. Despite the importance of genetic diversity and its growing recognition, conservation of genetic diversity, particularly aspects of local adaptation are often neglected in conservation prioritization and field level management owing to the fact that intraspecific genetic diversity is difficult to measure at large scales (Laikre, 2010; Fan *et al.*, 2018). However, the Aichi Target 13 under the CBD and post-2020 GBF have emphasized on the genetic diversity. Minter *et al.* (2021) and Hoban *et al.* (2021) highlighted that most countries recognized the maintenance of genetic variation, mainly in agriculture or forestry species, and used primarily *ex situ* approaches to genetic conservation. *Ex situ* approaches are usually implemented at a last resort and contain just a glimpse of overall species genetic diversity. In the present time of rapidly changing environmental conditions and enhanced human disturbances, greater attention to conservation of genetic diversity in wild species in their natural environment is needed. In past two decades or so, a number of concepts *viz.*, Forest gene banks (Uma Shaanker and Ganeshaiah, 1997; Uma Shaanker *et al.*, 2002); Evolutionary hotspots (Fan *et al.*, 2018); Genetic diversity hotspots (Deng *et al.*, 2019); and Gene Conservation Units (Hubert and Cottrell, 2014; Minter *et al.*, 2021; EUFORGEN, 2021) have evolved and been documented. These approaches are being briefly described below:

13.1.3

Forest Gene Banks

The careful scrutiny of the concept on forest gene banks, introduced by Uma Shaanker and Ganeshaiah (1997) revealed that the introduced concept pertains to an *in situ* site conservation that serves as a repository of genes in a 'sink' from as many diverse 'donor' or 'source' populations of the species as possible to represent the widest possible spectrum of genetic variability. Hence, the concept of forest gene bank envisages introduction, bulking, and growing of genetic diversity away from their site of origin. Thus, in view of the evolving concepts of genetic diversity, the requirement to maintain diversity at gene level in a wild species in its natural environment is not fulfilled in the approach introduced by Uma Shaanker and Ganeshaiah (1997), instead it is an *ex situ* conservation approach wherein introduction of propagules from one population to another, allowing mixing the populations has been advocated. Uma Shaanker *et al.* (2002) in their paper have also highlighted caveats and rejoinders relevant to maintaining genetic diversity away from its site of origin or gene flow from one population to the other by way of gene mixing. The conservation biologists view that introduction of propagules from one population into another or gene mixing may have deleterious effects by way of outbreeding depression, loss of alleles due to competition, and even disruption of local adaptive differentiation due to human induced gene flow from one population to the other. Dole and Sun (1992) were of the opinion that if populations are genetically well differentiated, the species is better conserved by conserving as many small units of population than mixing several populations. Conservationists also fear that introduction of genes in a population may cause an overall erosion of the genetic variability. In contrast, a number of proponents of the gene mixing or introduction school, on the other hand have argued in favor of artificial dispersal of seeds among populations to increase gene flow or to minimize inbreeding and to maximize genetic variability (Ralls *et al.*, 1988; Waser, 1993; Uma Shaanker *et al.*, 2002). Vrijenhoek *et al.* (1985) while advocating gene mixing, cautioned that the introduction of genes be between neighboring populations only, so that the wider genetic differences among the distantly separated populations are maintained. Often, genetic rescue operations using artificial migrations from *ex situ* reserves may be necessary when genetic diversity of a population is threatened and the wild species is showing signs of inbreeding. The approach of gene mixing and its consequences on shift of allele frequency need to be investigated in view of the emerging concepts and enhanced understanding of the genetic diversity. The proposed approach by Uma Shaanker and Ganeshaiah (1997) and Uma

Shaanker *et al.* (2002) in case of forest gene banks primarily aims at enriching the total genetic diversity at a designated sink site with the possibility of evolving diversity.

13.1.4

Evolutionary Hotspots

Traditionally, the concept of 'biodiversity hotspots' as a strategy towards conservation of the greatest biodiversity at the least cost has evolved and developed mainly around the 'species distribution patterns' highlighting areas which are most concentrated with the species distribution, have the most obvious endemism, and also have aggregation of the most endangered species (Myers, 1988 and 1990; Myers *et al.*, 2000). Despite genetic diversity within a species is a fundamental level of biodiversity and is an approximation of the evolutionary potential of an organism, the intraspecific (within and among populations) genetic diversity has been neglected in conservation planning and prioritization (Vandergast *et al.*, 2008). In recent years, a number of studies have proposed different approaches to map patterns of intraspecific genetic diversity across landscapes and regions with high evolutionary potential (evolutionary hotspots, i.e., regions with high within and among genetic diversity (Vandergast *et al.*, 2008; Fan *et al.*, 2018; Zampiglia *et al.*, 2019). These powerful approaches not only provide an avenue to readily incorporate measure of evolutionary processes into GIS based systematic prioritization and complementing traditional biodiversity hotspot identification but also provide positive correlation between species diversity and multiple species genetic diversity. Hence, the approach of evolutionary hotspot may provide potential for simultaneous conservation of both species' diversity and genetic diversity, and this way the species richness can be taken as a surrogate of genetic diversity in conservation planning (Kahilainen *et al.*, 2014; Fan *et al.*, 2018). The study by Fan *et al.* (2018) emphasized for establishing strong linkages and connectivity between existing PAs so as to facilitate gene flow and prevent the loss of intraspecific genetic diversity owing to genetic drift and inbreeding in isolated populations as a conservation priority.

13.1.5

Genetic Diversity Hotspots

Intraspecific genetic variation not only affects biodiversity patterns at varied hierarchical levels of biological organization but also feeds to the vital evolutionary process. It also provides populations with the potential to adapt to change in their biotic and abiotic environment (Chiocchio *et al.*, 2021). Accordingly, a major research arena has involved the identification of hotspots of intraspecific genetic diversity, that is, geographic regions harboring exceptionally high diversity and increasingly recognized as key targets in conservation biology. Souto *et al.* (2014) have defined genetic diversity hotspots as 'areas where multiple species have high genetic diversity and/ or contain unique genetic variants, and may be used to set conservation priorities'. Correct identification of intraspecific genetic diversity hotspots is a key step in designing effective strategies for the long-term persistence of populations in the face of global change. The traditional concept of biodiversity hotspots describes species richness, endemism, threat, or a combination of these 'at a coarse scale', while the 'fine scale' approach based on the definition of genetic diversity hotspots having high intraspecific polymorphism and unique variants, representing their evolutionary potential and evolutionary novelties, respectively (Souto *et al.*, 2014). Jenkins *et al.* (2013) have emphasized that fine scale methods are needed that integrate genetic information on numerous taxa within a given area at a scale in which regional decisions are made about the conservation investments and efforts. Spatially explicit molecular data have great potential but it has not been exploited for conservation planning. In the present biodiversity crisis, the priority is to evolve a common conservation strategy so as to protect the most species per dollar invested in conservation actions (Naidoo *et al.*, 2006). Looking for genetic hotspots could be a useful tool as more genetic data becomes available. In recent years, landscape genetics has made efforts to integrate population genetics, landscape ecology and a variety of spatial statistics. Certainly, a simple but novel fine scale GIS based approach defining genetic hotspots as documented by mapping molecular diversity of widespread trees can also be applied in the design and establishment of science based protected areas that may better preserve the evolutionary potential of habitats and species (Souto *et al.*, 2014).

13.1.6

Gene Conservation Units

In situations wherein diverse forests have been overburdened due to traditional resource use, and also suffer on account of varied human induced disturbances, and face unprecedented levels of uncertainty owing to climate change and the impact of new pests and pathogens, it is important to ensure that forests are not only adapted to current condition but have the capacity to adapt to future conditions. This can be achieved by retaining the genetic diversity and evolutionary potential of populations of FGR species so that natural selection and gene flow can act to allow them to adapt to new conditions (Hubert and Cottrell, 2014). Moreover, in view of the long-term nature of forestry, the adaptive genetic diversity within forestry species is of paramount importance. Hence, there has been an increasing interest in developing approaches that aim to conserve the genetic diversity of FGR species. One approach of dynamic genetic conservation of forest trees and FGR species is to manage specific areas that are able to maintain a diverse group of mating individuals and populations across different environmental gradients so as to ensure continued evolutionary processes. The EUFORGEN, a pan-European program/ network supports the development of genetic conservation policies and the practical implementation of gene conservation for forestry purposes (EUFORGEN, 2021). As a part of this wider program, the UK is committed to maintain and encourage genetic diversity within tree populations and it is reflected in *The UK Forestry Standard*. Accordingly, forestry practitioners in UK are encouraged to establish Gene Conservation Unit (GCU) and form a network of such units. A gene conservation unit has been defined as 'a clearly mapped area of forest or woodland where dynamic gene conservation is one of the main management priorities for one or more tree species' (Hubert and Cottrell, 2014). The dynamic gene conservation approach emphasizes the maintenance of evolutionary processes within tree populations to safeguard their potential for continuous adaptation.

The aim of establishing GCUs is broadly for two purposes: (a) maintenance of genetic diversity in large tree populations, and (b) conservation of adaptive or other traits in marginal or scattered populations, which often consist of only a few trees. The Forestry Commission, UK has provided detailed guidelines on establishing and managing GCUs (Hubert and Cottrell, 2014). The guidelines stipulate that management of long-lived trees for genetic conservation requires long-term commitment, planning and action. Generally, forest working/ management plans might only operate over a 10-year timescale, establishing a GCU would involve a strategic management commitment ideally for a longer period of 20 years or more. The minimum requirements for a successful GCU envisage that: (a) at least one tree species should be recognized in the management plan as the target species for genetic conservation in each unit while a GCU can have multiple target species within it; (b) each target species must meet the appropriate minimum population size; (c) GCU should have a recognized status as a genetic conservation area and should be part of a wider database; and (d) a basic plan in case of GCU is key for allowing management interventions. The GCU can consist of pure or mixed species stands. No genetic material of the target species of unknown origin or which is not adapted to the local condition should be present. Each GCU should be defines as a fixed area within a forest covering one or more compartments. The unit should be large enough to contain a sufficient number of effective mating and reproducing trees to prevent reduction of genetic diversity through demographic bottlenecks and inbreeding. *The UK Forestry Standard* envisage that a GCU must meet one of the two criteria relevant to minimum requirements in terms of population size. If the purpose of the unit is to maintain the genetic diversity of a widely occurring and stand-forming conifer or broadleaf species, the GCU must consist of at least 500 reproductive trees and may be about 3-6 hectares in size so as to contain 500 mature trees. However, if the objective of the unit is to conserve adaptive traits in marginal or scattered tree populations (scattered conifers or broadleaf species), the GCU must harbour a minimum of 50 trees of reproductive age of the target species or, in the case of dioecious tree species (e.g., *Taxus baccata*), 50 seed bearing trees and 50 pollen producing trees. The area of GCU in such case will depend on the degree to which the target species is scattered and will therefore have to be considered on a case-by-case basis (Hubert and Cottrell, 2014). The central database on GCUs must incorporate two types of data. Firstly, an essential data for each of the GCU covering aspects like State/ UT, unit number, latitude, longitude, minimum and maximum elevation, area of the unit, and account of tree species growing in the unit (both target and non-target species). Secondly, data on target species covering aspects like the scientific names of target species, unit establishment year, conservation category (in situ or ex situ), population origin (autochthonous or native/ indigenous species, introduced or unknown), justification for GCU (maintain genetic diversity in large tree populations or conserve specific adaptive and/ or phenotypic traits in marginal or scattered tree populations having small population size), and total number of reproducing trees in GCUs (51-500, 501-5,000, and > 5,000). The guidelines on GCU have also emphasized on monitoring so as to ensure that GCU is fit for the purpose it was established. Regular and annual monitoring was recommended to observe that GCU still serve its dynamic conservation purpose and have not been damaged or destroyed by human activity or biological (e.g., disease outbreak) or other environmental factors. In addition, every 5 or 10 years, periodic assessments through field inventories are required so as to check the survival, health and regeneration success of the target species or any other biotic activity that might have taken place (Hubert and Cottrell, 2014). On almost similar lines, the Biodiversity International and APFORGEN have collectively issued the guidelines for identifying GCUs and seed sources for Asian trees (BI and APFORGEN, 2019). These guidelines elaborate on the process of identifying 4-tiers of genetic conservation sites and seed sources.

The foregoing description has amply revealed that above stated approaches towards in situ genetic conservation are relatively new, emerging and evolving besides they have almost similar thrust. Among them, the approach of GCU adopted by EUFORGEN and Forestry Commission, UK appears to be more scientific, practical, feasible and justifiable on the face of changing environmental conditions. Considering these merits of GCU, the pilot project in Uttarakhand has provisioned for the establishment of GCUs in the forested landscapes, hereby named as the 'Forest Genetic Conservation Units (FGCUs)' utilizing the insight generated based on molecular characterization of five prioritized FGR species. These efforts will be pioneer in nature and the experience gained and lessons learned in due course will ultimately provide the much-desired direction for the establishment of a network of genetic conservation units in the country for conservation of FGR species.

13.2

Ex Situ Conservation

A wide range of alternative approaches principally static in nature and in contrast to the above described dynamic *in situ* conservation, and as also elaborated in section 1.11.9.2. has been documented and being implemented in the arena of agriculture, horticulture and forestry. In the context of plant genetic resources, varied *ex situ* conservation approaches emerged by the mid-twentieth century and evolved thereafter as a reaction to the rapid decline of agricultural biodiversity mainly due to the replacement of landraces and native varieties by improved and hybrid crop varieties. Lately, it was realized that on one hand, these approaches have immensely helped in enhancing productivity but on the other hand, such efforts resulted into considerable loss of genetic diversity. Advances in molecular markers and technologies have opened new vistas in providing greater insight into the spatially explicit inter and intra population variability among a wide range of plant species. A large number of forestry species are marginal or peripheral as they have scattered distribution with small population size. In addition, several species often suffer on account of asynchrony in male and female plants, poor seed set or empty seeds, fragmentation, and poor regeneration. Low genetic diversity resulting in such situations due to inbred populations, loss of alleles owing to genetic drift and genetic erosion, and lack of gene flow among populations demand alternative static *ex situ* approach of conservation. Amongst varied existing *ex situ* conservation approaches, establishment of field gene banks is one of the prominent techniques and useful strategy for plant genetic conservation (Yunus, 2001). In this approach, genetic variation is maintained away from its original location and samples of a species, sub species, or variety are transferred and conserved as living collections. The approach of field gene bank is of great relevance and the most common method of conserving genetic resources of species, especially with recalcitrant seeds and vegetatively propagated plants. In field gene bank (FGB), plant genetic resources are kept as live plants and they undergo continuous growth and require maintenance (Saad and Nordin, 2001). FGBs are often subjected to human disturbances, natural disasters or even adverse environmental conditions. With the advent of molecular characterization, plants introduced and conserved in FGB require sufficient understanding of some of the genetic principals of plant genetic resources exploration and conservation, especially those related to the structure and distribution of the genetic diversity of the species to be conserved as well as the genetic diversity of the materials that are being conserved (Nordin and Saad, 2001). Over the years, in view of rapidly growing insight on genetic considerations, the emphasis has shifted from collecting species specific genotypes or populations for immediate use, to collecting representative samples of the extant variability for conservation and use, both now and in the near future. The IPGRI, Malaysia has published a detailed training manual on the establishment and management of FGB providing a background, choice of materials, factors in layout, genetic considerations, and problems and challenges in their management (Saad and Rao, 2001). The suggested protocol on the establishment of FGB by Saad and Rao (2001) is more or less similar to the above-mentioned *ex situ* approach on forest genebank as advocated by Uma Shaanker and Ganeshaiah (1997). The principle and the field layout/ activities resemble in these approaches with minor differences in nomenclature.

13.3

Circa situm Conservation

The growing literature on varied aspects of forestry or forest conservation amply reveals that in general, human activities in the forested regions around the world, particularly in the tropics are on an increase, and in future, it will be difficult to conserve several important tree species owing to enhanced negative human impact. It will only be possible to conserve such important tree species if they are managed *circa situ* in farm lands. However, prohibiting expense of maintaining live genebanks for taxa with large growth forms and the time required to regenerate species with long generation intervals, among other factors often encourage farmers to cut down trees on agricultural lands and reduce forest remnants in their extent so as to maximize agricultural production. Loss of forest and woodland is a practical concern for rural communities in the tropics that have traditionally depended on them for various resources (FAO, 2010). Garrity (2004) stated that agroforestry practices which integrate trees with annual crop cultivation, livestock production and other farm activities have received increasing attention as an alternative to support livelihoods and ecosystem functions. Trees in farmland in neighboring forest fragments, when present, also support population of insects, birds, and other organisms needed for crop pollination and biological pest control adding to the crop productivity. Zomer *et al.* (2009) documented that more than 1.2 billion people practice agroforestry and around 560 million people live in farm landscapes with 10 per cent or more tree cover. Gradually, the potential of agroforestry and value of agroforestry ecosystems in providing insurance to farmers for their crops against natural calamities, enhanced and assured income besides role of biodiversity (pollinators, seed dispersers, pest regulators, etc.) dependent on forest remnants/ agroforestry woodlots have been recognized. Trees are able to provide the structural diversity to sustain associated fauna in agricultural landscapes, which are needed for critical functions in agricultural production (Dawson *et al.*, 2009). Despite the recognized importance and significance of forest remnants/ woodlots, small and marginal farmers in human dominated countries like India are unable to maintain remnant patches of forests and avail their varied advantages due to small landholdings.

Considering that agroforestry trees and remnant forest patches provide varied products including food, fodder, fuel, timber, medicines besides a wide array of services including soil fertility replenishment, shade, water, catchment protection and the fixation of carbon, and they also have key role in tree conservation, Dawson *et al.* (2013) investigated the relevance of small holders agroforestry systems for conserving tropical tree species and genetic diversity in *circa situm, in situ* and *ex situ* settings. Thus, they considered the links between agroforestry and tree conservation in three different settings and elaborated on the role of agroforestry in *circa situm* conservation and other two broad approaches (*in situ* and *ex situ*) and remarked that decisions about the long-term value of agroforests for *circa situm* conservation of tree species diversity should clearly not be based on the current levels of species diversity alone. Rather the occurrence and abundance of exotic trees, transitions in diversity that are determined by regenerational behavior and density dependent reproductive biology, and methods of production and market development, are all important factors in determining value. Further, based on the detailed investigations and an exhaustive review on the influence of agroforestry and circa situm conservation on *in situ* and *ex situ* conservation, Dawson *et al.* (2013) concluded that connectivity between widely dispersed, low-density trees in agricultural landscapes is not only central for *in situ* and *ex situ* conservation but also in determining the success of *circa situm* approach in tree and FGR species conservation along with improving farmer's access to a diversity of tree germplasm that they are interested in planting.

13.4

Objectives

In view of the relevance of above described three approaches to FGR conservation, and their interconnections, the pilot project's Component on FGR Conservation and relevant to this chapter, specifically envisaged: (a) establishment of FGR Conservation Areas (FGR-CAs) in natural forests for species of high conservation concern (target-CAs for 5 species); (b) establishment of field genebanks of priority FGR species (target-5 species); and (c) survey and assessment of remnant populations of important FGR for *circa situm* conservation on private lands. In light of the above detailed description on Forest Gene Conservation Units (FGCUs), their relevance and global recognition as a measure of *in situ* conservation, the present task aim to establish 28 such units in the context of five prioritized FGR species for which genetic diversity hotspots were identified based on their molecular characterization (see chapter 10). Altogether, six Field Gene Banks (FGBs) in the context of six prioritized FGR species were established as *ex situ* conservation measure. In addition, field level studies in select villages of Uttarakhand were included from the perspective of developing an insight on the *circa situm* repository of FGR species conserved in remnant forests/ and or planted trees/ agroforest patches. The following objectives were set-forth for the sub-component:

(i) Identify and establish *in situ* forest gene conservation units of prioritized FGR species for long term conservation of species.

(ii) Identify seed source populations of prioritized FGR species, collect germplasm, produce starting plant material and establish field gene banks.

(iii) Assess the status of FGR species in *circa situm* conservation efforts in agricultural landscape.

13.5

Materials and Methods

Specific material and methods employed towards *in situ* and *ex situ* conservation of prioritized species, and for ascertaining the status of *circa situm* conservation efforts of FGR species by local people in agricultural landscapes are described below one by one:

13.5.1

Establishment of *In situ* Forest Gene Conservation Units (FGCUs)

Five prioritized FGR species including *Quercus semecarpifolia* (Kharsu oak), *Myrica esculenta* (Kafal), *Taxus wallichiana* (Thuner), *Betula utilis* (Bhojpatra), and *Rhododendron arboreum* (Burans) were selected for the purpose of establishment of FGCUs in each case. As already stated, all these selected species are ecologically and economically important and are under varied degree of human pressures and influence of climate change for their existence. The microsatellite-based marker technology was adopted to analyse the genetic diversity by assessing allelic richness, and presence of unique alleles in the range of distribution of these species in the Uttarakhand State. Various genetic parameters studied through molecular characterization have already been described in Chapter 10 and details on methods adopted, results, and key findings were elaborated. The outcomes of varied analyses revealed several populations which have been referred as genetic diversity hotspots in the range of distribution of each species based on the respective allelic richness and presence of unique alleles. The identified areas need protection from further deterioration of the valuable alleles possessed by them and ultimately the genetic diversity. The best option is to designate these genetic diversity hotspots as the Forest Gene Conservation Units (FGCUs) for the purpose of long term *in situ* conservation of genetic diversity exhibited by prioritized FGR species and so as to allow natural selection, adaptive capacity and evolutionary processes in case of each prioritized tree species. The foregoing description specific to FGCU has already elaborated on its purpose, functions, potential size, safeguard mechanism and monitoring needs. For India, this is the pioneer effort towards the establishment of FGCUs in case of five FGR species through the pilot project. The responsibility for the establishment, maintenance and monitoring of recommended FGCUs lies on the Uttarakhand Forest Department as UKFD is the primary custodian of forests in the State.

13.5.2

Establishment of *Ex situ* Field Gene Banks (FGBs)

Establishment of *ex situ* FGBs in collaboration with UKFD involved the following key steps:

13.5.2.1

Prioritization and Species Selection

Suitability of the species for establishment of field gene banks as *ex situ* conservation strategy was prioritised and decided through the consultative process involving eminent forest officers, ecologists, geneticists and botanists and considering the ecological and economic status of the species. The prioritization process allowed selection of six FGR species *viz., Diploknema butyracea, Rhododendron arboreum, Myrica esculenta, Cinnamomum tamala, Taxus walichiana* and *Toona ciliata* for the purpose of establishment of FGBs as a part of the Component on FGR Conservation under the pilot project.

13.5.2.2

Identification of Seed Source Populations, Germplasm Collection and Propagation

The review of literature focusing on forest working plans, scientific reports, and published research papers, followed by an extensive consultative process, and field surveys in different FDs/ PAs within Uttarakhand allowed an understanding on the ecological distribution and physical health status of the species of concern. Phenotypically superior and healthy seed sources were identified and the corresponding germplasm was collected. All species were propagated asexually/ vegetatively, except *M. esculenta* and *T. ciliata* which were propagated by seed. Propagation of most of the species was done in the nurseries of FRI, Dehra Dun, except in case of species like *T. wallichiana* and *M. esculenta* wherein the propagation was carried out at Kaddukhal Nursery of Narendranagar FD. Seedlings of one year age were used for establishment of the FGBs.

13.5.2.3

Site/ Land Identification and Plantation

Despite the fact that 45.44 per cent area of the State is under forest cover, it was difficult to find suitable land under the control of UKFD for the establishment of proposed FGBs as forest areas are under burden of resource dependence or the department has a wide range of commitments for either its own activities or with varied user agencies. The sites were carefully identified in consultation with UKFD for the establishment of FGBs and required field areas were allocated for the purpose in different FDs.

13.5.2.4

Protection Measures

The young plantations of prioritized FGR species in the established FGBs were required to be protected from wild animals, especially from porcupine, wild pig, etc. besides human disturbances such as livestock grazing, forest fires, etc. Thus, various kinds of protection measures adopted as per the situation of respective forest areas and in view of the recommendations of the local forest officer are described below:

- The entire area of field gene bank (0.6 ha) of *D. butyracea* (Chyura) and *R. arboreum* (Burans) were covered and protected with chain-link fencing.
- The area of 0.6 ha each for *M. esculanta* (Kafal), *C. tamala* (Tej Patta) and *T. ciliata* (Tun) were protected by Barbed fencing.

However, the area of about 0.6 ha for the field gene bank of *Taxus baccata* (Thuner) was protected by the stone wall boundary as this area belongs to the very high altitude and falls under the Nandadevi

Biosphere Reserve / National Park Forest Division, Joshimath. (Uttarakhand) where no other protection measures are allowed.

13.5.2.5

Field Preparation and Earth Work

The UKFD has allocated about 0.6 ha area of forest land in selected FDs for the establishment of each FGB with net area of 0.5 ha. The selected field sites for the proposed FGBs in the respective FDs were first cleared by removing the undesirable shrubby vegetation and weeds. As per the decided layout, pits (45 cm x 45 cm) were demarcated and dug out nearly a month before the plantation time so as to allow retention of sufficient moisture in them during the rainy season. The area of each FGB was protected well before plantation either by chain link fencing or barbed wire fencing as per the local requirement so as to prevent damage by wild and domestic animals. Mainly, the Randomized Block Design (RBD) was used for establishment of FGB in case of *D. butyracea, R. arboreum, M. esculenta, C. tamala,* and *T. wallichiana* while the Augmented Block Design (ABD) was adopted in case of *Toona ciliata.*

13.5.3

Assessment of FGR Species in *Circa situm* Remnant Forests in Select Villages

As already stated, *circa situm* conservation is a farmer-based conservation approach in rural, human modified agricultural landscapes comprising habitations, home gardens, agricultural lands with forest remnant patches/ planted trees, and agroforest woodlots outside natural habitats but within a species native geographical range. Remnant forests as *circa situm* repository have greater role in FGR conservation. As a part of the sub-component on *circa situm* conservation, field surveys were carried out to assess the status of forest trees conserved on farms as a source of fodder, fuelwood and for other household purposes. Generally, villagers/ farmers retain mature trees or remnant forest patches. The present task specifically assessed the diversity of FGR species in forest remnants/ planted forests occurring in agricultural landscapes.

Present study, thus, assessed the status of remnant populations of tree species conserved in 20 select villages, having nearly 3,200 households, represented by different communities. The objective of the questionnaire and sample-based household surveys was to collect information about the occurrence of species, use pattern of FGR by the habitants, and about tree species which were planted, grown and conserved for varied end uses *viz.*, timber, fuelwood, fodder, medicinal, and other uses. Mostly head of the family or any other person in the family were interviewed. The household survey was followed by field surveys so as to record the presence and absence of FGR species in different house areas, agriculture fields and rural landscape of the village. The household surveys in different villages and field level observations allowed developing an insight on the occurrence of FGR species, resource use pattern, and dependence on FGR.

13.6

Key Findings, Recommendations and Achievements

The following section describes recommendations for the establishment of Forest Gene Conservation Units (FGCUs) based on the findings of molecular characterization of five prioritized FGR species for *in situ* conservation of genetic diversity hotspots; highlights achievements in terms of the establishment of Field Gene Banks (FGBs) as *ex situ* conservation measure; and summarizes results of *circa situm* conservation based on household surveys and field observations:

13.6.1

Recommendations for *In situ* Conservation and the Establishment of FGCUs

The multifarious lab-based investigations pertaining to molecular characterization of five prioritized tree species as described in Chapter 10 yielded valuable insight on genetic diversity hotspots on the basis of allelic richness (Rs) and presence of unique alleles (PRs) in sampled populations. Accordingly, altogether 28 FGCUs are recommended for the establishment by UKFD (Table 13.1). This includes seven FGCUs each in case of *Q. semecarpifolia* and *R. arboreum*, followed by five FGCUs each for *M. esculenta* and *T. wallichiana*. Four FGCUs are recommended in case of *B. utilis*. Table 13.1 provides details on populations which were identified to be conserved as FGCUs based on corresponding higher values of Rs and PRs besides relevant variables specific to recommended locations (latitude, longitude, altitude, compartment, beat, range, and forest division). Details of these recommendations were provided to UKFD. Locations of recommended FGCUs in case of five FGR species are also shown in Fig. 13.1. Species-wise recommendations are provided below:

(i) *Quercus semecarpifolia* (Kharsu Oak): Out of 24 sampled populations, seven populations showed high genetic diversity and these seven populations represented five different FDs/ PAs (Pithoragarh, Gangotri, Chakrata, and Upper Yamuna FDs, and Kedarnath WLS). Pithoragarh FD registered the highest presence of three genetically diverse populations (QS15- Munsiyari, QS24-Himkhola and QS23- Narayan Ashram). Besides Pithoragarh FD, one population each from remaining three FDs (QS11-Bhukkitop, Gangotri; QS19- Mundhola, Chakrata; QS09- Radi Top, Upper Yamuna); and 1 PA (QS21- Pinswar, Kedarnath WLS) were recognized as genetically diverse hotspots in the context of *Q. semecarpifolia* (Table 13.1). These seven identified populations need priority attention and the pilot project recommends for the establishment of FGCUs in these genetically rich and unique sampled populations (Fig. 13.1).

Sr. No.	Populations with Codes	Compartment	Beat	Range	Forest Division
***Quercus semecarpifolia* (Kharsu Oak)**					
1.	Munsiyari (QS15)	3	Khalia	Munsyari	Pithoragarh
2.	Bhukkitop (QS11)	5c	Bhukki-I	Taknaur	Gangotri
3.	Mundhola (QS19)	9	Punal	Deoghar	Chakrata
4.	Pinswar (QS21)	4	Kalishila	Ukhimath	Kedarnath WLS
5.	Raditop (QS09)	4	Tiyan	Mugarsanti	Upper Yamuna
6.	Himkhola (QS24)	6	Hiragomri First	Dharchula	Pithoragarh
7.	Narayan Ashram (QS23)	NA	NA	Dharchula	Pithoragarh
***Myrica esculenta* (Kafal)**					
1.	Bhowali (ME17)	7a	Ninglat-II	Bhowali	Nainital
2.	Shitla-khet (ME16)	NA	NA	Almora	Almora
3.	Takula (ME15)	NA	NA	Almora	Almora
4.	Sandev (ME08)	5c	Sandev	Didihat	Pithoragarh
5.	Mayali (ME18)	NA	NA	South Jakholi	Rudraprayag
***Taxus wallichiana* (Thuner)**					
1.	Darma Valley (TW21)	NA	NA	Dharchula	Pithoragarh
2.	Har ki Dun (TW19)	5	Har ki Dun	Har ki Dun	Govind WLS
3.	Mornaula (TW18)	10a	NA	North Gola	Nainital
4.	Himkhola (TW15)	6	Hiragomri-I	Dharchula	Pithoragarh
5.	Mundhola (TW12)	9	Punal	Deog har	Chakrata
***Rhododendron arboreum* (Burans)**					
1.	Badhanital (RA19)	6	Badhani	North_Jakholi	Rudraprayag
2.	Dhanaulti (RA22)	4	Kaddukhal	Saklana	Narendranagar
3.	Chaurangi Khal (RA11)	29b	Dhotri-IV	Mukhem	Gangotri NP
4.	Ghes (RA23)	NF	NF	Pindar East	Badrinath
5.	Dunagiri (RA16)	NA	NA	Dwarhaat	Almora
6.	Gwaldam (RA24)	6a	Sarkot	Pindar Central	Badrinath
7.	Chirbatiya (RA18)	7b	Tharti	Bhilangana	Tehri
***Betula utilis* (Bhojpatra)**					
1.	Triyugi Narayan (BU10)	5	Triyugi Narayan-II	Ukhimath	Kedarnath WLS
2.	Himkhola (BU06)	9	Hiragomri- II	Dharchula	Pithoragarh
3.	Darma Valley (BU11)	NF	NF	Dharchula	Pithoragarh
4.	Rudranath (BU01)	2	Rudranath East	Gopeshwar	Kedarnath WLS

NA- Not Available

(ii) *Myrica esculenta* (Kafal): Five populations out of total 23 sampled populations of *M. esculenta* were considered as genetically rich and unique. These genetically prioritized populations represented four FDs *viz.*, Almora with two populations (ME16- Shitla Khet, and ME15- Takula); and one each from Nainital (ME17- Bhowali); Pithoragarh (ME08-Sandev); and Rudraprayag (ME18-Mayali) forest division. Details of proposed FGCUs in case of 5 prioritized populations are provided in Table 13.1 and their locations are shown in Fig. 13.1.

	Latitude(N)	Longitude(E)	Altitude(m)	Rs	Prs
	30°3'49.737"	80°12'37.377"	3,063	9.77	0.69
	30°50'28.44"	78°39'37.446"	2,802	9.65	0.52
	30°56'27.297"	77°45'20.5"	2,708	9.59	0.48
	30°35'8.207"	79°7'26.856"	1,963	9.29	0.42
	30°45'19.506"	78°12'33.297"	2,685	9.13	0.43
	30°1'53.058"	80°38'51.742"	3,007	8.78	0.53
	29°58'40.157"	80°39'21.017"	2,794	8.69	0.33
	29°24'53.845"	79°32'18.664"	2,022	15.06	1.70
	29°35'44.4"	79°33'18.255"	1,612	14.98	1.24
	29°43'56.44"	79°41'52.471"	1,442	14.64	0.47
	29°48'57.799"	80°13'5.425"	1,703	14.47	0.94
	30°23'24.824"	78°53'38.075"	1,716	14.02	0.95
	30°10'28.928"	80°34'33.564"	2,879	9.41	0.78
	31°7'40.5"	78°23'42.973"	3,363	8.76	0.46
	29°26'27.16"	79°45'52.881"	2,191	8.50	0.67
	30°1'41.167"	80°38'51.291"	2,837	8.31	0.36
	30°56'27.552"	77°45'16.703"	2,710	7.72	0.92
	30°29'40.927"	78°56'46.102"	2,454	12.69	0.82
	30°24'14.803"	78°18'0.745"	2,381	12.44	0.47
	30°38'9.655"	78°29'15.242"	2,064	12.35	0.57
	30°8'36.443"	79°43'8.773"	2,376	11.89	0.74
	29°49'0.844"	79°26'57.411"	2,121	11.83	0.99
	30°1'32.836"	79°34'41.455"	1,905	11.21	0.99
	30°22'55.02"	78°50'7.01"	2,050	10.78	1.61
	30°37'33.622"	78°55'37.883"	3,386	10.79	2.23
	30°3'3.748"	80°38'59.957"	3,675	10.23	1.49
	30°12'19.696"	80°32'59.761"	3,133	10.04	2.05
	30°31'12.327"	79°19'15.268"	3,343	10.00	1.68

Table 13.1 Recommended Populations of Five Prioritized Species for the Proposed Establishment of Forest Gene Conservation Units (FGCUs)

(iii) *Taxus wallichiana* (Thuner): Out of 21 sampled populations of *T. wallichiana* across the State of Uttarakhand, five populations were considered of higher conservation priority in view of their genetic diversity and uniqueness (Table 13.1). These priority conservation populations represent three FDs and one PA. Pithoragarh FD harboured two priority populations (TW21- Dharchula, and TW15- Himkhola). Nainital and Chakrata FDs harboured TW18- Mornaula, and TW12- Mundhola populations, respectively. The Govind Wildlife Sanctuary also harboured one of the genetically diverse populations (TW19- Har ki Dun). The pilot project proposes to establish FGCUs for these five identified priority populations (Fig. 13.1).

(iv) *Rhododendron arboreum* (Burans): Seven populations of *R. arboreum* out of total 27 sampled populations across the Himalayan State of Uttarakhand were found genetically diverse based on molecular characterization. These identified genetically rich and unique populations need priority *in situ* conservation by way of the establishment of proposed FGCUs in each case. Among seven prioritized populations, RA19- Badhanital, Rudraprayag FD was ranked the highest in terms of its genetic diversity based on allelic richness while RA18- Chirbatiya, Tehri FD was recognized as genetically unique on the basis of highest value of private alleles. In addition, one population each from Narendranagar FD (RA22- Dhanaulti); Almora FD (RA16- Dunagiri); Gangotri NP (RA11- Chuarangi Khal); and two populations from Badrinath FD (RA23- Ghes and RA24- Gwaldam) emerged as genetically important populations from the perspective of *in situ* conservation and establishment of FGCUs as proposed in Table 13.1 and shown in Fig. 13.1.

(v) *Betula utilis* (Bhojpatra): Out of total 11 sampled populations of *B. utilis* in the State, four populations *viz.*, BU10- Triyugi Narayan from Kedarnath WLS; BU06- Himkhola and BU11- Darma Valley from Pithoragarh FD; and BU01- Rudranath from Kedarnath WLS emerged as genetically diverse hotspots. Thus, these populations need priority attention by way of the establishment of proposed FGCUs in each case as detailed in Table 13.1 and shown in Fig. 13.1.

Fig. 13.1 Recommended Sites for the Proposed Establishment of Forest Gene Conservation Units (FGCUs) in Context of Five Prioritized FGR Species

FD - Forest Division
WD - Wildlife Division
NP - National Park
WLS - Wildlife Sanctuary
TR - Tiger Reserve
BR - Biosphere Reserve

13.6.2

Management Prescriptions for the Proposed FGCUs

As already stated in the foregoing introduction of the present Chapter, the concept of identification of genetically diverse hotspots in the context of FGR species and their *in situ* conservation is new for India. However, European countries and EUFORGEN have been advocating and implementing the establishment of a network of *in situ* gene conservation units. The UK Forestry Commission has envisaged that a GCU must meet one of the two criteria relevant to minimum requirements in terms of population size. If the purpose of the unit is to maintain the genetic diversity of a widely occurring and stand-forming conifer or broadleaf species, the GCU must consist of at least 500 reproductive trees and may be about 3-6 hectares in size so as to contain 500 mature trees. However, if the objective of the unit is to conserve adaptive traits in marginal or scattered tree populations (scattered conifers or broadleaf species), the GCU must harbour a minimum of 50 trees of reproductive age of the target species or, in the case of dioecious tree species (e.g., *Taxus baccata*), 50 seed bearing trees and 50 pollen producing trees. The area of GCU in such case will depend on the degree to which the target species is scattered and will therefore have to be considered on a case-by-case basis (Hubert and Cottrell, 2014). The Chapter 5 on ecogeographic mapping has revealed that five FGR species under consideration *viz., Q. semecarpifolia, M. esculenta, T. wallichiana, R. arboreum,* and *B. utilis* have estimated eco-distribution area of 832.4 km^2, 477.26 km^2, 545.86 km^2, 617.48 km^2, and 305.16 km^2 respectively. Certainly, these five species have relatively wider distribution in terms of estimated extent of eco-distribution area amongst 50 studied FGR species. Hence, in larger forest divisions, it is not difficult to set aside a minimum of 5 hectares of forest area in case of each species and corresponding proposed FGCUs wherein the species has its wider natural distribution range. The respective field manager of corresponding FD/ PA needs to carefully identify adequately large forest sites having $\geq$ 500 mature reproductive trees and which are preferably in the forest interiors and likely to be least disturbed by local biotic pressure or any other developmental activity with the sole purpose of maintaining genetic diversity of these prioritized species for allowing adaptive and evolutionary process to take place in changing climate and other environmental conditions. Identified forest lands for the purpose of FGCUs need to be carefully delineated around the geocoordinates provided in Table 13.1 and designated as FGCUs. Newly established FGCUs need to be well protected with proper demarcation. Once FGCUs have been established, they need mention in respective Forest Working Plan, awareness among frontline staff, protection and monitoring on periodic basis (*see section 13.1.6*). As far as possible, all established FGCUs with their geocoordinates should become the part of forest database maintained by the UKFD and FGR Database at FRI and kept free from recurrent forest fires, livestock grazing, cutting, lopping, and any other type of human induced disturbance.

13.6.3

Establishment of *Ex situ* Field Gene Banks (FGBs)

Saad and Rao (2001) have provided a detailed account in a training manual on the establishment and management of field gene bank. Uma Shaanker and Ganeshaiah (1997) and Uma Shaanker *et al.* (2002) have also elaborated on a new approach to conserve forest tree genetic resources wherein genetic diversity from different sources (donor populations) of a species can be maintained in 'sink population' or the recipient population, but they have named this approach as the forest gene banks which confuses with the afore-described forest gene conservation units. As envisaged by the pilot project, Field Gene Banks (FGBs) of six prioritized FGR species *viz., R. arboreum, M. esculenta, T. wallichiana, D. butyracea, C. tamala,* and *T. ciliata* have been established in different FDs/ PA of Uttarakhand (Fig. 13.2). Out of this, molecular characterization was carried out in case of the former three species while field surveys across the State of Uttarakhand undertaken as a part of the pilot project allowed getting an insight on phenotypically superior populations in case of latter three species. Details on the seed sources/ germplasm in case of each species used in the establishment of respective FGB are summarized below one by one (Table 13.2).

(i) ***Rhododendron arboreum:*** The germplasm of *R. arboreum* belonged to four seed sources *viz.*, Pauri, Tehri, Uttarkashi, and Chakrata FDs and was planted in RBD with three replications and plant spacing of 4 m × 4 m at Compartment No. 04, Thali, Devidhura Forest Range, Champawat FD (Fig. 13.2).

(ii) ***Myrica esculenta:*** The germplasm of *M. esculenta* belonged to three distinct and diverse seed sources *viz.*, Askot, Pithoragarh FD; Devidhura, Champawat FD; and Khirsu, Pauri FD and planted in RBD with three replications with plant spacing of 3 m × 3 m at Compartment No. 23, Bhowali Forest Range, Nainital FD (Fig. 13.2).

(iii) ***Taxus wallichiana:*** Seed sources of *T. wallichiana* were diverse and belonged to the populations of Chakarata FD; Ghangariya, Valley of Flower NP; Dayara Bugyal, Uttarkashi FD; and Joshimath FD and were planted in RBD with three replications and plant spacing of 4 m × 4 m at Malari Beat, Suraithota Section, Joshimath Forest Range, Nanda Devi National Park (Fig. 13.2).

Table 13.2 - Details of Field Gene Banks Established for *Ex situ* Conservation of FGR Species

Sr. No.	Species	Location of Established FGB	No. of Seed Sources/ Germplasm
1.	*Rhododendron arboreum*	Compartment No.04, Thali, Devidhura Forest Range, Champawat FD	04 Pauri, Tehri, Uttarkashi, Chakrata
2.	*Myrica esculenta*	Compartment No. 23, Bhowali Forest Range, Nainital FD	03 Askot, Devidhura, Khirsu
3.	*Taxus wallichiana*	Malari Beat, Suraithota Section, Joshimath Forest Range, Nandadevi NP	04 Chakrata, Ghangariya, Dayara bugyal, Joshimath
4.	*Diploknemma butyracea*	Compartment No. 25, Chida, Kali Kumaon Range, Champawat FD	04 Champawat, Pithoragarh, FRI, Almora
5.	*Cinnamomum tamala*	Compartment No. 3, Rushi, Nalena-II Forest Range, Nainital FD	04 Nainital, Khirsu, Pithoragarh, Ringalgarh
6.	*Toona ciliata*	Village Maikhura, Chamoli	24 Genotypes

RBD - Randomized Block Design; ABD - Augmented Block Design

(iv) *Diploknemma butyracea:* Seeds of *D. butyracea* were collected from four seed sources *viz.*, Champawat FD; Pithoragarh FD; FRI, Dehra Dun; and Almora FD and were planted in RBD with three replications and plant spacing of 4 m × 4 m at Compartment No. 25, Chida, Kali Kumaon Range, Champawat FD (Fig. 13.2).

(v) *Cinnamomum tamala:* The field gene bank of *C. tamala* comprises of the germplasm of three phenotypically diverse seed sources *viz.*, Nainital FD; Khirsu, Pauri FD; Pithoragarh FD, Ringalgarh, Tehri FD and established following RBD with four replications and plant spacing of 4 m × 4 m at Compartment No. 3, Rushi, Nalena-II Forest Range, Nainital FD (Fig. 13.2).

(vi) *Toona ciliata:* The germplasm of *T. ciliata* consisted of 24 phenotypically superior and diverse genotypes belonging to Uttarakhand and were planted in ABD with three blocks and plant spacing 5 m × 5 m at Village Maikhura, District Chamoli (Fig. 13.2).

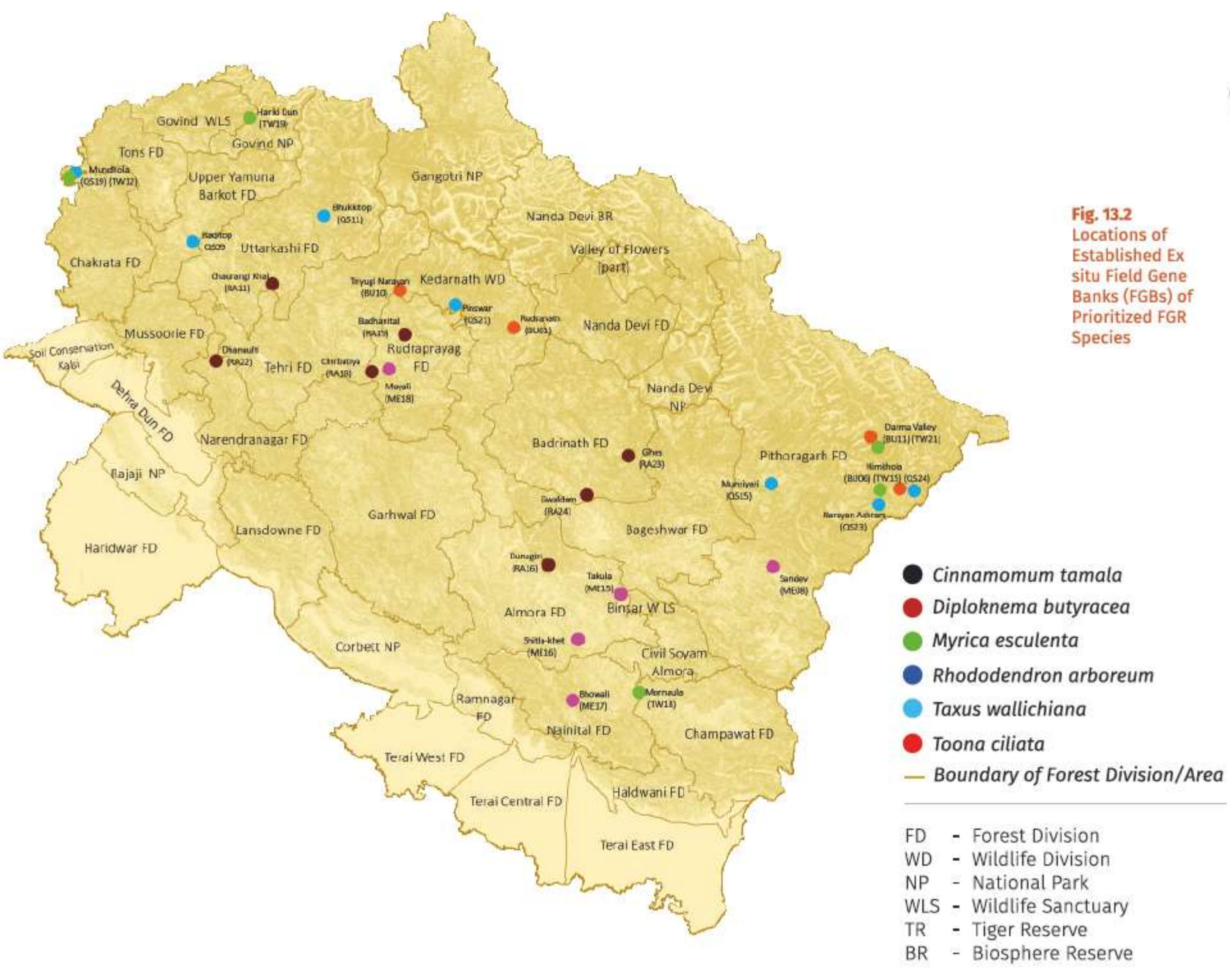

Fig. 13.2 Locations of Established Ex situ Field Gene Banks (FGBs) of Prioritized FGR Species

	Geo- Location (Latitude, Longitude and Altitude)	No. of Plants	Spacing	Design	Replication	Date of Plantation
	N 29°26'50.3"E 79°46'57.0" Alt- 2161 m	375	4 m × 4 m	RBD	03	21/08/2020
	N 29°23'25.1"E 79°27'40.7" Alt- 1564 m	375	4 m × 4 m	RBD	03	19/08/2020
	N 30°42'2.161" E 79°52'0.367" Alt- 3514 m	520	3 m × 3 m	RBD	04	13/09/2020
	N 29°29'40.4"E 80°05'49.8" Alt-1098 m	375	4 m × 4 m	RBD	03	10/08/2020
	N 29°21'27.0"E 79°27'25.0" Alt- 1700 m	620	3 m × 3 m	RBD	04	20/08/2020
	N 30°15' 52.35"E 79°16' 10.10" Alt- 1760 m	125	4 m × 4 m	ABD	04	24/07/2020

13.6.4

Circa situm Conservation

Two broad approaches of conservation (*in situ* and *ex situ*) which are in practice for considerable time have their own advantages and limitations. Mostly, these two approaches for plant/ FGR/ biodiversity conservation are being practiced by public agencies and on public lands. However, in the context of forest species, particularly FGR, *circa situm* conservation on private/ community lands especially in human dominated landscapes has pivotal role in strengthening and augmenting efforts towards conservation of FGR. Traditionally, local communities, farmers and villagers have been either retaining natural forest patches while clearing lands for agriculture, or have been planting some select tree, shrub, and woody climber species which provide multiple products and services. In several instances, small forest parcels are being set aside as sacred groves and several tree species are culturally and religiously important, and are considered revered and worshipped. The varied roles played by forest remnant patches/ planted forests or agroforestry woodlots on rural/ agricultural landscapes have been highlighted earlier. In the Himalayan State of Uttarakhand, local people have been conserving a wide range of forest trees and other associated species for a variety of uses. Hence, the Component of the Pilot Project on FGR Conservation assessed the diversity of FGR species on farmlands and the rural landscapes. Household surveys and field level observations in rural landscape revealed that as many as 19 tree species were found as choice and conserved on farmlands, agroforestry woodlots, around the habitations in the rural landscape. The village-wise occurrence of 19 tree species in Garhwal and Kumaon regions is summarized in Table 13.3. A minimum of four species and maximum of eight species were recorded from forest remnants/ planted trees within sampled villages (Table 13.4).

Out of 19 species, highly preferred and conserved species based on the frequency of occurrence were *Grevia optiva, Rhododendron arboreum, Quercus leucotrichophora, Cinnamomum tamala*; moderately preferred species are *Juglans regia, Celtis australis, Prunus armeniaca, Zanthoxylum armatum, Pyrus pashia, Bergenia ciliata, Prunus domestica, Ficus auriculata, Toona ciliata, Alnus nepalensis*; and least preferred and conserved species are *Myrica esculenta, Prunus cerasoides, Pinus roxburghii*, and *Melia azedarach* (Table 13.4). Among 19 species, *J. regia, M. esculenta, P. domestica*, and *P. armeniaca* are important fruit tree species in the region. Five species *viz., Q. leucotrichophora, G. optiva, M. azedarach*, and *C. australis* are being used for fodder purpose. *P. roxburghii* and *Q. leucotrichophora* are considered as important timber species. Wood of *T. ciliata* and *J. regia* are being used for making furniture and in wood carving works, respectively. Wood of *P. pashia* and *P. cerasoides* is used for making walking sticks. *G. optiva* and *R. arboreum* provide fuelwood. Wood of *P. roxburghii* and *R. arboreum* is used for making charcoal. Leaves and bark of *C. tamala* are important spices. *Berberis* spp., *B. ciliata*, and *F. auriculata* have medicinal value. Flowers and fruits of *R. arboreum* and *M. esculenta* are being used for making squash, respectively. Most of these species are part of 250 FGR species prioritized for Uttarakhand, the pilot demonstration State, except three species *viz., Bergenia ciliata, Prunus armeniaca*, and *Prunus domestica*.

Table 13.3
Occurrence of FGR Species in Select Villages of Garhwal and Kumaon Regions of Uttarakhand

Village	Latitude (N)	Longitude (E)	Forest Species
A. Garhwal Region			
Maikhura, Chamoli	30.2684	79.2719	*J. regia, M. esculenta, R. arboreum, A. nepalensis, Z. armatum, P. cerasoides, T. ciliata*
Animath, Joshimath	30.5347	79.5684	*A. nepalensis, T. ciliata, P. roxburghii, Q. leucotrichophora, T. ciliata*
Gadora, Chamoli	30.4174	79.4394	*M. azedarach, C. australis, G. optiva, F. auriculata, B. variegata*
Narayanbagad, Chamoli	30.1285	79.3887	*J. regia, M. esculenta, R. arboreum, A. nepalensis, Z. armatum, P. cerasoides*
Dewal, Chamoli	30.0580	79.5806	*J. regia, P. pashia, P. armeniaca, P. domestica, Z. armatum, G. optiva, R. arboreum, Q. leucotrichophora*
Helang, Chamoli	30.5285	79.5213	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Niti, Chamoli	30.7775	79.8408	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
B. Kumaon Region			
Bagad, Nainital	29.4235	79.4270	*C. australis, Berberis spp., B. ciliata, G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Malabagad, Nainital	29.4332	79.4132	*C. australis, B. ciliata, G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Dhunaghat, Champawat	29.3796	79.9679	*C. australis, Berberis spp., B. ciliata, Grevia optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Lohaghat, Champawat	29.4035	80.0764	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Bhimrada, Champawat	29.3013	79.9238	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Basan, Champawat	29.4894	80.0951	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Majheda, Pithoragarh	29.5040	80.1593	*J. regia, P. pashia, P. armeniaca, P. domestica, Z. armatum, G. optiva, R. arboreum, Q. leucotrichophora*
Beda, Pithoragarh	29.4990	80.1758	*J. regia, P. pashia, P. armeniaca, P. domestica, Z. armatum, G. optiva, R. arboreum, Q. leucotrichophora*
Kafligair, Bageshwar	29.7478	79.7438	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*
Nagla, Bageshwar	30.0712	79.9877	*J. regia, P. pashia, P. armeniaca, P. domestica, Z. armatum, G. optiva, R. arboreum, Q. leucotrichophora*
Jagdishpur	29.0559	79.3597	*J. regia, P. pashia, P. armeniaca, P. domestica, Z. armatum, G. optiva, R. arboreum, Q. leucotrichophora*
Kapkot, Bageshwar	29.9450	79.8995	*G. optiva, R. arboreum, Q. leucotrichophora, C. tamala*

Table 13.4 - Village-wise Occurrence of FGR Species in *Circa situm* Repositories

Sr. No.	Species	Maikhura	Animath	Gadora	Narayanbagad	Dewal	Helang	Niti	Bagad	Malabagad	Dhunaghat	Lohaghat	Bhimrada	Basan	Majheda	Beda	Kafligair	Nagla	Jagdishpur	Kapkot	Total
1.	*A. nepalensis* (Utis)	+	+		+																3
2.	*Berberis* spp. (Kilmora)											+	+	+							3
3.	*Bergenia ciliata* (Pathar Chatta)											+	+	+							3
4.	*Celtis australis* (Khadik)			+		+	+					+	+	+							6
5.	*Cinnamomum tamala* (Tejpatta)							+		+	+	+	+	+	+	+	+			+	9
6.	*Ficus auriculata* (Timala)			+		+	+														3
7.	*Grevia optiva* (Bheemal)			+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	15
8.	*Juglans regia* (Akhrot)	+			+	+	+		+									+	+		7
9.	*Melia azedarach* (Bakain)			+																	1
10.	*Myrica esculenta* (Kaphal)	+			+																2
11.	*Pinus roxburghii* (Chirpine)		+																		1
12.	*Prunus armeniaca* (Khumani)					+			+						+	+		+	+		6
13.	*Prunus cerasoides* (Payan)	+			+																2
14.	*Prunus domestica* (Plum)								+									+	+		3
15.	*Pyrus pashia* (Mahal)								+									+	+		3
16.	*Quercus leucotrichophora* (Banj Oak)		+					+	+	+	+	+	+	+	+	+	+	+	+	+	13
17.	*Rhododendron arboreum* (Burans)	+			+			+	+	+	+	+	+	+	+	+	+	+	+	+	14
18.	*Toona ciliata* (Toon)	+	+																		2
19.	*Zanthoxylum armatum* (Timru)	+			+				+									+	+		5
	Total	7	4	4	6	5	4	4	8	4	4	7	7	7	5	5	4	8	8	4	

13.7

Future Prospects

The rapidly evolving subject of genetic conservation in the context of FGR species is altogether a new dimension for a vast country like India having enormous diversity of forest ecosystems. Present Chapter has specifically dwelt upon *in situ*, *ex situ* and *circa situm* conservation initiatives in this regard. The following section deliberates about the future prospects of these three distinct but interconnected approaches one by one:

13.7.1

In situ Genetic Conservation

In past three decades or so, especially since the inception of Convention on Biological Diversity, notable progress has been made towards policy, legal, management, institutional, governance, and monitoring support required for *in situ* and *ex situ* conservation of biological resources. Thus, a wide range of innovative approaches have been implemented across the globe and considerable progress has been made towards conservation and restoration of ecosystems and species. Increasingly, the CBD targets, particularly post-2020 Global Biodiversity Framework emphasize not only on '*in situ* conservation of genetic resources' but also stress on 'protecting genetic diversity within all wild species'. Importance of intraspecific genetic diversity in providing populations with capacity to adapt to changing environmental conditions and to challenges from novel pest and diseases has also been lately realized and considered as a key aspect for genetic conservation. In short, newer insight focusses on conserving genetic diversity for mitigating biodiversity loss and in order to overcome issues related to lower fitness, and higher loads of pathogens and infectious diseases on account of reduced or loss of genetic diversity. Despite the importance of conserving genetic diversity, it is rarely reflected adequately in policy, law and conservation management. Although, several country reports to CBD, and wider policies and laws (e.g., National Forest Policy, National Wildlife Action Plan, Wildlife (Protection) Act, Biological Diversity Act) in the context of India mention about maintaining genetic diversity and variation, this primarily focused on RET species and *ex situ* conservation measures. Certainly, the main perceived barrier to implementing *in situ* genetic conservation management of a wide array of wild plant and animal species is lack of specific desired knowledge on individual species in terms of their distribution, population structure, population size, genetic variation, gene flow mechanism, and reasons for genetic erosion. In addition, generation of desired knowledge on these stated varied aspects that too for an enormous array of wild plant and animal species occurring widely in their natural environments.

Minter *et al*. (2021) have reviewed the current global application of *in situ* genetic conservation management techniques, especially whether Gene Conservation Units (GCUs) are effective for conserving evolutionary potential in a wide range of taxa and their current implementation. They found that genetic conservation is being implemented in 158 species, mostly trees and other plants, and the most common program was establishment of a GCU. As stated earlier, the EUFORGEN promotes conservation of genetic resources through a pan European strategy for the establishment of GCUs, resulting in over 3,200 GCUs harbouring more than 4,000 populations of about 100 tree species. Moreover, these GCUs were selected to protect genetic resources of economically important plant species including about 100 tree species (Minter *et al*., 2021). Obviously, current efforts at the global level in view of the overall plant and FGR diversity is a diminutive figure. Although, India has made notable progress towards *in situ* conservation of her vast diversity of wild plants and FGR species across different biogeographic zones by setting aside considerable number of PAs and managed forests, it is yet to pay required attention to inter and intra genetic diversity within wild plant and FGR species. Firstly, it requires desired information and knowledge on genetic diversity. Secondly, generation of information and knowledge will need resolute support at the highest level for provisioning of required manpower and financial resources for the fulfillment of targets of this pivotal and gigantic task.

In view of the above, India needs to urgently develop a system for *in situ* genetic conservation that can co-exist with current management practices (e.g., PAs, managed forests), and one that may alliance with proposed expansion of 'Other Effective Area-Based Conservation Measures (OECMs)' as suggested by the CBD (CBD, 2018). Thus, the pilot project on conservation of FGR in Uttarakhand has made pioneer efforts in identifying genetic diversity hotspots in case of five prioritized tree species, and the foregoing description has accordingly recommended to establish 28 FGCUs as a new initiative on the lines of GCUs promoted by EUFORGEN. Being altogether a new dimension for the country, establishment and management of recommended FGCUs will provide not only experience but direction to evolve an effective guideline for expanding the network of FGCUs and covering as many as possible wild FGR species. Initially, the guidelines and experience disseminated by EUFORGEN can be used in this regard and in due course, country's own guidelines need to be developed. Proposed guidelines on FGCUs need to be co-developed with forest practitioners, scientists, and land managers/ owners. Merit in exploring the feasibility of extending policy to cover all species would be desirable so as to cover neglected non-target species also. In absence of desired experience in the field of genetic conservation that too relevant to the country, boundaries of proposed FGCUs need to be flexible, accounting for dispersal distances, with adaptable criteria to suit species characteristics such as population size and geographical scale. Concerns about likely shift in species range on account of climate change and displacement of populations uphill need consideration. The proposed FGCUs need to be integrated with current practices of PAs, MFs and OECMs instead of a stand-alone effort. The flexible approach can be adopted for each target species or group of target species. The universal 'rule of thumb' on minimum size of a genetically viable population may be difficult to put in practice as these numbers will vary considerably among taxa. Thus, the threshold for population size for inclusion in a FGCU needs to be taxon specific and computed using information on the species biology, distribution, and current status. The ultimate goal of FGCUs needs to ensure that these genetic units are operationalized in case of targeted species so as to encourage dynamic gene conservation by recognizing appropriate breeding populations in a geographic area and to manage these populations to promote normal cycles of natural regeneration to occur besides allowing persistence of the focal species, mitigate genetic threats, and connecting up habitats to increase gene flow.

13.7.2

Ex situ Genetic Conservation

Ex situ genetic conservation has an important role to play considering the fact that a large number of wild FGR species are already threatened and several others are in the process to join the assemblage of this group owing to sparse distribution, small population size, inbred populations, and restricted gene flow. *Ex situ* gene conservation has definite potential to rescue inbred populations and safeguard the existing gene-pool of rare and unique alleles of the targeted species by way of static conservation through introduction, admixing, etc. This approach has its own limitations as well as several caveats from the conservation community that needs consideration. When the discipline of molecular characterization and the concepts of genetic diversity are evolving at a rapid pace, the *ex situ* genetic conservation approach needs to be promoted only in the event when a species has lost its genetic variation and at risk of local extinction that too with utmost care and scientific basis. Further, such efforts need to have inbuilt monitoring so as to prevent any adversity arising on account of such interventions.

13.7.3

Circa situm Genetic Repository

It is widely accepted among the fraternity of conservationists that: (a) large reserves retain more species than small ones; (b) reserves with a small boundary in relation to area retain more species of the natural habitat than those with long or irregular boundaries; (c) linking reserves with corridors is an effective way to enhance the size of reserves; and (d) multiple reserves provide a hedge against catastrophic loss (Recher *et al*., 1987). These concepts have emerged from the theory of island biogeography and conservation biology. The growing science of landscape ecology aptly reflects that the human dominated landscapes in tropical countries are under continuous influence of human disturbances, reflecting fast changing heterogenous spatial pattern. The PAs, MFs and other conservation areas are embedded in the 'matrix' of rural agricultural setup. In most instances, these reserves are inadequate in size, have large interface, and incompatible land use in the surrounds. Often, they are unable to conserve all the values for which they were established. In view of this, the foregoing description has adequately highlighted the vital role of *circa situm* conservation. Remnant forests/ original large forest trees left in the clearings by the traditional farmers are being used as perching sites by both migratory and resident birds. Frugivorous birds drop or regurgitate seeds and fruits which fall under the canopies of remnant trees, thus contributing to an accumulation of species which make these remnant trees into 'regeneration nuclei' (Guevara *et al*., 1986). This way clump distribution of select species is evident in human modified landscapes. Remnant trees thus operate as 'recruitment foci' and resulting into primary succession. The sites underneath the remnant trees are rapidly colonized by the woody species, and conditions are favourable for the establishment of primary and late secondary forest trees. Moreover, remnant forest patches/ trees, and even agroforestry woodlots provide some connectivity in otherwise fragmented population of a species.

Considering the fact that landscapes in a country like India are being transformed rapidly and FGR species in small and isolated forest reserves (PAs and MFs) may face conservation issues in time to come, it is of utmost importance to pay much desired attention on conservation of *circa situm* repository of FGR species. So far, botanists, ecologists, conservationists, and practicing foresters have paid attention in terms of vegetation assessments in prominent PAs and other reserves. The field of *circa situm* conservation in the Indian context is grossly unattended. Hence, there is a priority to promote landscape ecology-based studies supplemented by phytosociology, vegetation ecology, and researches on the role of pollinators and seed dispersers in the maintenance of remnant forests besides their evaluation from the socioeconomic perspective and cultural significance.

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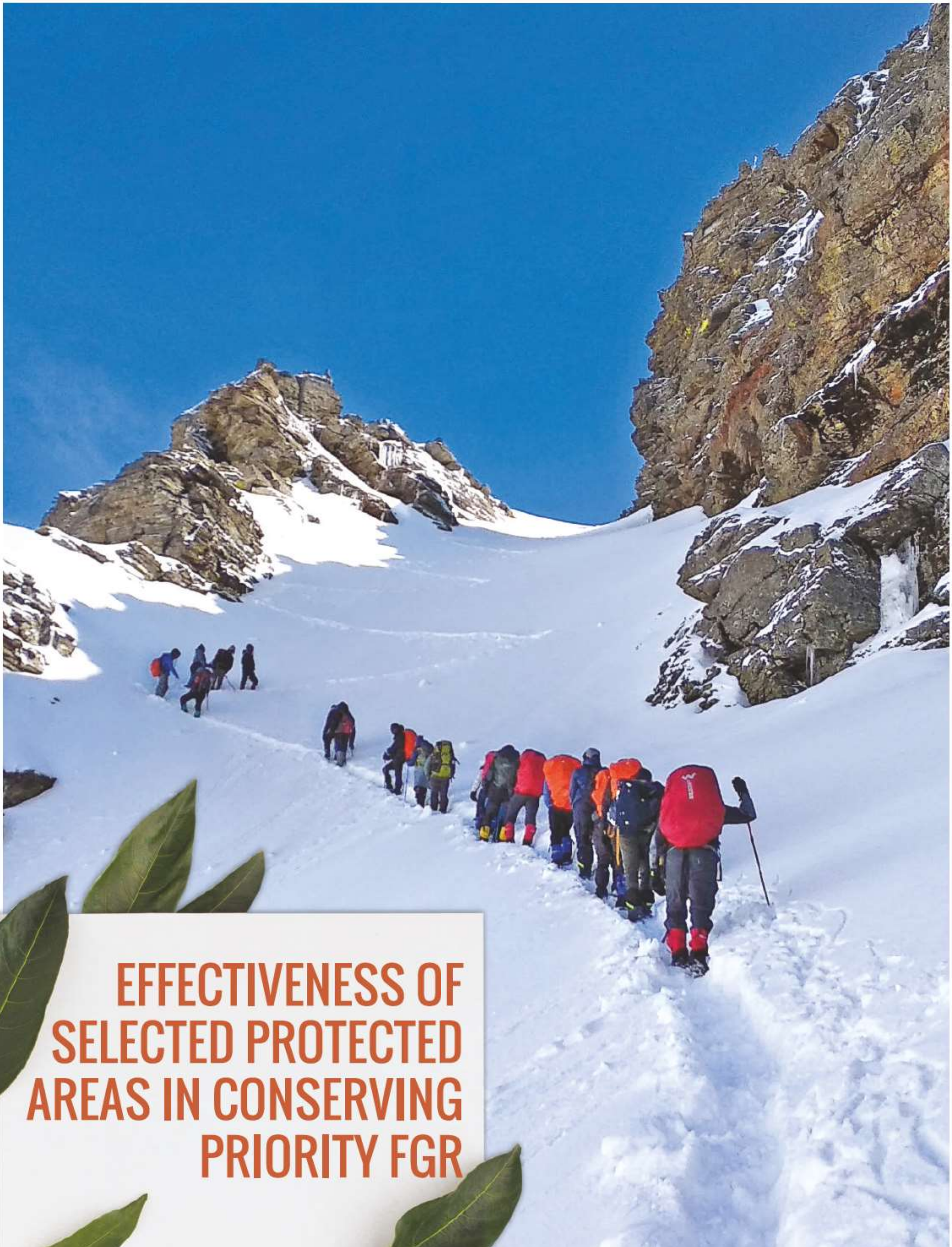

EFFECTIVENESS OF SELECTED PROTECTED AREAS IN CONSERVING PRIORITY FGR

14

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Forests are home to many of the world's most diverse ecosystems and repository of biodiversity. Since millennia, humans have transformed the forested landscapes with the expansion of agriculture and more recently the expansion of urban infrastructure. Nearly, one-third of the world's forests have been lost to human land use (Ritchie and Roser, 2021). Hence, forests are one of the most threatened ecosystems. Protecting the world's forests is central to the conservation of biodiversity, especially forest genetic resources. Protecting places or setting aside specific areas that are special in terms of natural or cultural significance or even of societal use, with the purpose of conserving them, has been a tradition for several centuries (CBD, 1992; Hummel *et al.*, 2019; McNeely, 2020). Importance of wildlife Protected Areas (PAs) for conserving nature has been well recognized across the globe. PAs are seen as the most important tools in conservation science and management (Chape *et al.*, 2005). Scientifically established, effectively managed and fairly governed PAs offer a wide range of solutions relevant to conservation of nature and cultural resources, protection of human health and well-being, provision of sustainable livelihoods, mitigation of climate change, and support to sustainable development (Hummel *et al.*, 2019). PAs have long been regarded as important areas for maintaining species and habitat diversity. Traditionally, conservation strategies have recognized species as the building blocks which have both, a functional and inherent value. Recently, the importance of intra and inter specific genetic diversity within and among species has received greater attention as they ensure to provide sustained flow of environmental services, productive values, adaptive capacity, and continuance of evolutionary processes (Hoban *et al.*, 2020). Globally, PAs help in conservation of varied forests and maintenance of genetic diversity within their complex structure and dynamics.

Conservation of not only species and habitats, but also genetic variability has become a renewed focus under the expectations that its loss could render populations and species less able to adapt to enhanced human disturbances resulting into ongoing environmental changes (Martin *et al.*, 2012). PAs or a network of PAs perform several functions including acting as refuges and or sanctuary for species, saving specific habitats, allowing ecological processes that would not persist in intensely managed landscapes, and for their ability to provide space for potential ecological restoration and natural evolution. In addition, PAs serve as a bench mark so as to assess the impact of human interactions with the environment (Hummel *et al.*, 2019).

According to the Convention on Biological Diversity, 'PA is a geographically defined area, which is recognized, dedicated, regulated and managed through legal or other effective means so as to achieve specific objectives of conserving nature along with associated ecosystem services and cultural values' (CBD, 1992).

Deguignet *et al.* (2014) documented that more than 2,00,000 sites meet the definition of a PA. Globally, 14.6 per cent of land has been designated as a PA (Ritchie and Roser, 2021). By 2015, 16 per cent of global forests fall within a legally established protected area. In case of important sites for terrestrial biodiversity, an increase from 33 per cent in 2000 to 46 per cent in 2017 was registered. Since the inception of CBD, PAs are considered essential in most national and international strategies and a large number of public, private, community and voluntary organizations are active in promoting the conservation of PAs having a wide array of conservation values. International networks of PAs (e.g., World Heritage Sites and Biosphere Reserves by UNESCO) have been established. The IUCN-World Commission on Protected Areas (IUCN-WCPA) is the world's premier network of protected and conserved areas expertise. The Commission has over 2,500 members spanning 140 countries who provide strategic advice to policymakers and work to strengthen capacity and investment for protected areas establishment and management (IUCN-WCPA, 2013). The UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is a global centre of excellence on biodiversity and nature's contribution to society and the economy, and maintains a database on protected areas across the world (IUCN-WCMC, 2016). The National Wildlife Database at the Wildlife Institute of India maintains information on PAs in different biogeographic zones and biotic provinces, and States and UTs in the context of India (Rodgers and Panwar, 1988). The establishment of comprehensive, biogeographically and ecologically representative, and effectively managed PA network is a critical strategy not only for conservation of biodiversity, but for securing ecosystem goods and services, enabling climate change, adaptation and mitigation, and helping countries achieve the sustainable development goals. The world's PAs have increased by nearly 60 percent, both in number and area, since the CBD came into force in 1993 (UNDP, SCBD & UNEP-WCMC, 2021).

National and State Governments besides UN Agencies (CBD, UNESCO, UNEP, FAO, UNDP, GEF), a wide range of governmental and non-governmental international agencies, and communities have not only set aside and established PAs, sacrificed revenues, and made huge investments towards their protection, legal support, management, capacity development, research, monitoring, and even relocation of people. Hence, the need to evaluate management effectiveness of PAs was realized in 1992 during the World Park Congress in Caracas, Venezuela in response to growing concern amongst PA professionals and the public that several PAs across the globe are failing to achieve their objectives, and in several instances, they are actually losing the conservation values for which they were established (Hockings *et al.*, 2006 and 2008; McNeely, 2020). In compliance to the emerging global concern, Hockings *et al.* (2006) provided a framework on 'Management Effectiveness Evaluation (MEE) of Protected Areas'. Coad *et al.* (2015) reported that only 17.5 per cent of the world countries have achieved the 60 per cent score of management effectiveness. India is among the select countries of the world that have institutionalized the MEE process and began evaluating management effectiveness of World Heritage Sites, PAs (NPs and WLSs), and Tiger Reserves in 2006 (Mohan *et al.*, 2020). Such a well-tested and validated MEE approach specific to conservation of FGR within PAs presently does not exist. Nevertheless, the pilot project has made preliminary efforts in view of the envisaged task and present findings in the present Chapter.

14.1

Protected Areas in Uttarakhand

The conservation movement seeks to manage and protect natural resources, known as 'nature conservation' is deep rooted in the Indian ethos, and in situ conservation of forests and other natural ecosystems has been recognized as the central activity towards biodiversity conservation. Despite human dominated country, India is one of the seventeen megadiverse countries and contributes about eight per cent of the known global biodiversity. Country has established a network of 987 PAs including 106 National Parks, 564 Wildlife Sanctuaries, 99 Conservation Reserves, and 218 Community Reserves, covering a total extent of 1,73,053.69 km2 and representing 5.26 per cent of its geographical area. The sections 1.11.9.1 and 1.11.9.3 have elaborated on the country's efforts towards in situ conservation, and the establishment and management of a network of PAs on a biogeographic basis.

The Himalayan State of Uttarakhand in view of its varied landforms, extremities of altitudinal variation and climate, diversity of forests/ vegetation and other ecosystems, river and water resources, and cultural heritage has also created a network of total 17 PAs comprising six (06) national parks, seven

(07) wildlife sanctuaries, and four (04) conservation reserves besides conservation areas *viz.*, two (02) Tiger Reserves (Corbett and Rajaji TRs), one (01) Biosphere Reserve (Nanda Devi BR), and one (01) Elephant Reserve (Shiwalik ER). Six NPs cover total 4,915.44 km^2 area and they represent 9.19 per cent geographical area of the State, while seven sanctuaries have cumulative extent of 2,690.04 km^2 or 5.03 per cent area of the State (Table 14.1). In addition, four conservation reserves collectively cover an extent of 160.01 km^2 and represent just 0.30 per cent GA of the State. Thus, the State has a network of PA covering 7,765.49 km^2, representing 14.52 per cent GA of the State (Table 14.1). Two Tiger Reserves *viz.*, Corbett (Core- 821.99 km^2; Buffer- 546.92 km^2) and Rajaji (Core- 819.54 km^2; Buffer- 255.63 km^2) with total extent of 1,368.91 km^2 and 1,075.17 km^2, respectively are important TRs in the State. The Shiwalik ER covers an extent of 6,404 km^2, while the Nanda Devi BR covers an area of 6,407.03 km^2. The Nanda Devi NP and Valley of Flowers NP are two world famous World Heritage Sites designated by UNESCO.

Table 14.1 Details on Protected Areas of Uttarakhand

Source Uttarakhand Forest Department, 2022

Sr. No.	Protected Area	Area (km^2)	Representation of Geographical Area (%)
A. National Parks			
1.	Corbett National Park	520.82	0.97
2.	Nanda Devi National Park	624.60	1.17
3.	Valley of Flowers National Park	87.50	0.16
4.	Rajaji National Park	820.42	1.53
5.	Gangotri National Park	2,390.02	4.47
6.	Govind National Park	472.08	0.88
	Sub-Total 'A'	4,915.44	9.19
B. Wildlife Sanctuaries			
1.	Govind Wildlife Sanctuary	485.89	0.91
2.	Kedarnath Wildlife Sanctuary	975.20	1.82
3.	Askot Wildlife Sanctuary	599.93	1.12
4.	Sonanadi Wildlife Sanctuary	301.18	0.56
5.	Binsar Wildlife Sanctuary	47.07	0.09
6.	Mussoorie Wildlife Sanctuary	10.82	0.02
7.	Nandhaur Wildlife Sanctuary	269.95	0.50
	Sub-Total 'B'	2,690.04	5.03
C. Conservation Reserves			
1.	Jhilmil Jheel Conservation Reserve	37.84	0.07
2.	Aasan Wetland Conservation Reserve	4.44	0.01
3.	Pawalgarh Conservation Reserve	5.82	0.01
4.	Nainadevi Himalayan Bird Conservation Reserve	111.91	0.21
	Sub-Total 'C'	160.01	0.30
	Grand Total	7,765.49	14.52

The average size of NPs in the country in January, 2022 was 418.60 km^2. The extent of six NPs in Uttarakhand ranged from as low as 87.50 km^2 (Valley of Flowers NP) to 2,390.02 km^2 (Gangotri NP). Thus, the average size of six NPs in Uttarakhand was 819.24 km^2 which is nearly double to the national average size of NPs. Likewise, the average size of sanctuaries in India was 217.21 km^2, while the average size of seven sanctuaries in the Himalayan State was 384.29 km^2. The overall average size of two prominent categories of PAs i.e., NPs and WLSs in the case of India was 249.07 km^2, while this value in case of Uttarakhand was 456.79 km^2. Certainly, the State has relatively larger PAs than the overall average size of PAs in the country. This is probably on the account of altitudinal variation and inaccessible rugged terrain mainly in the Greater and Middle Himalayas. The altitudinal gradient, and varied aspects and landforms result into diversity of forest types, and it requires that this assemblage of forest types is adequately protected. Nevertheless, PAs in Uttarakhand, particularly in higher altitudinal range prior to their establishment used to receive substantial transhumance domestic sheep and goat and this migratory livestock used to exert immense pressure on forest resources, especially in temperate forests, sub-alpine forests, and alpine pastures. The developmental pressure by way of expanding/ widening of roads, highways and border roads, hydropower projects, growing urban centers, and increasing tourism activities in surrounding lands also have some adverse impact on PAs and their conservation values.

14.2

Management Effectiveness Evaluation (MEE) of PAs

The Management Effectiveness Evaluation (MEE) in the context of PAs (NPs and WLSs) has been defined as the assessment to judge that how well these PAs are being managed- primarily, whether they are protecting their values and achieving the goals and objectives agreed upon (Mohan *et al.*, 2020). The term 'management effectiveness' mainly reflects: (a) issues relevant to design of PA, (b) adequacy and appropriateness of management system and processes, and (c) delivery of the objectives of PA, including conservation values. In short, six elements: (i) context, (ii) planning, (iii) inputs, (iv) processes, (v) outputs, and (vi) outcomes inbuilt in MEE not only assess protected area design and planning, but also assess conservation significance, threats, policy environment, resources to carry out management, suitability of management processes, management inputs, services and products and overall impact (Stolton *et al.*, 2007). The robust and comprehensive approach of MEE enables and support an adaptive approach to management besides assists in effective resource allocation. The MEE promotes accountability and transparency, it also helps in involving the community and build constituencies. Ultimately, outputs and outcomes of MEE promote the values of evaluated PAs. Four cycles of MEE in the context of TRs and one round of MEE in case of NPs and WLSs in the State of Uttarakhand have been completed along with similar exercises in other States/ UTs. Thus, the MEE scores and specific recommendations provided by the MEE Committees are available and they offer greater insight on the varied aspects relevant to management effectiveness of TRs and PAs (Mohan *et al.*, 2020).

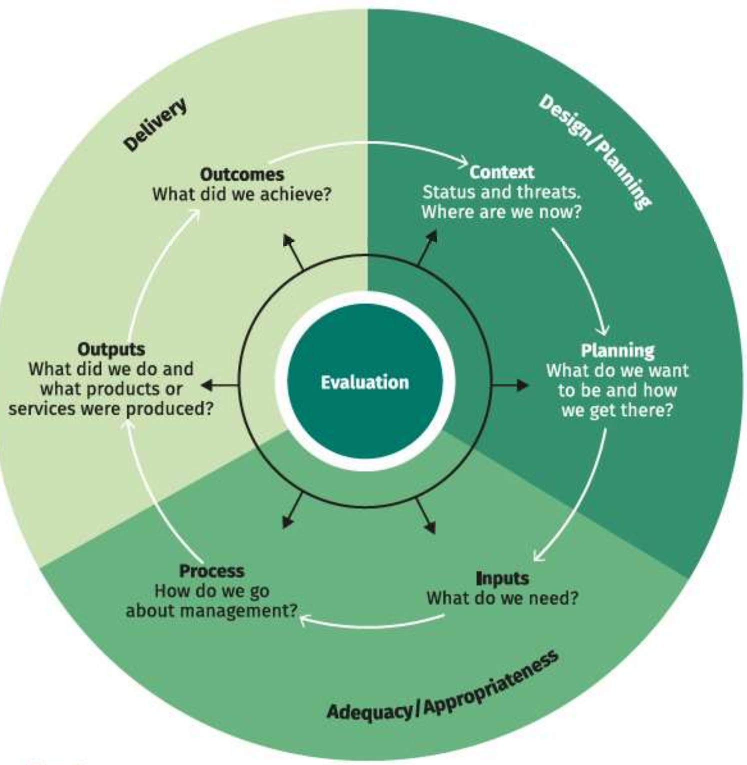

Fig. 14.1 The Process of Management Effectiveness Evaluation in the Context of Protected Areas

Source: Hockings *et al.* (2006)

14.3

Management Effectiveness Evaluation for FGR

Forest Genetic Resources, particularly trees, shrubs, and climbers; their germplasm and inter and intra-specific genetic variability among and within the species are as such an inbuilt part of different forested landscapes, more specifically diverse forest ecosystems and relevant PAs established for the purpose of conservation of representative biodiversity of the biogeographic area. Indeed, FGR in a forest are responsible not only for creating the habitat for themselves but also offer habitats to a wide array of plant and animal species and maintain ecological and evolutionary processes including adaptive capacity of FGR species. As stated earlier in the Chapter 13, the maintenance of broader goals pertaining to the genetic and species diversity in FGR conservation complements with the global agenda on habitat and ecosystem protection for biodiversity conservation through PA management. In short, PAs as core activity to *in situ* approach of conservation helps in the maintenance of representative biodiversity of an area and natural pool of genetic variability, and persistence of varied ecological processes. It is well recognized that forest-based large PAs cover greater diversity of forest types and associated plant and animal species including FGR. The principles of island biogeography, conservation biology, and landscape ecology all are relevant in case of PA management. The countrywide exercise on MEE in the context of PAs in past two decades or so thus provide the insight on the current situation of PAs, their management, threats, constraints, challenges, and emerging needs. Indirectly, the well-established MEE process in the context of PAs will offer some insight on the status of FGR also. However, management effectiveness evaluation in case of FGR species will need to consider 'intrinsic risk factors' *viz.*, population structure, rarity/ density, regeneration capacity, dispersal ability, habitat affinities and genetic variation. In addition, the 'external risk factors' *viz.*, pest and pathogen threats, habitat shift pressure, and disturbances on account of human activities will need appropriate consideration in formulating a comprehensive strategy on MEE specific to FGR. Further, variables relevant to 'conservation modifiers' such as endemism, and conservation status are of utmost importance, and they can be also part of management effectiveness evaluation strategy. The Forest Tree Genetic Risk Assessment System, a tool for conservation decision making developed by Potter and Crane (2010) can be of immense utility in devising a comprehensive MEE strategy in the context of FGR species.

In light of the foregoing description, and considering the fact that FGR are widely distributed in the managed forests, Van Panchayats, and other private/ community owned forests/ tea or coffee estates or agroforestry woodlots (*circa situm* conservation), it would be wise that the CoE-FGR, FRI plan a consultative workshop involving various stakeholders (policy and decision makers, forest practitioners, conservationists, botanists, forest scientists, entrepreneurs, and local communities) with the intention to deliberate and develop a robust and comprehensive MEE process in the context of FGR.

14.4

Objectives

The Component on Conservation of FGR under the Pilot Project has envisaged evaluation of selected PAs for their effectiveness in conserving priority FGRs by way of floristic survey and phytosociological studies. In view of the afore described evolving concept of MEE in case of FGR, and specific envisaged task on the sub-component in the Pilot Project, the following objectives were set forth for the envisaged studies:

(i) Assess the potential ecogeographic distribution of prioritized FGR species in PAs of Uttarakhand.

(ii) Undertake floristic surveys and carry out phytosociological studies in select PAs of Uttarakhand.

14.5

Methodology

Following methodology was adopted relevant to above stated two objectives:

14.5.1

Review of Secondary Information

All PAs and FDs are mandatorily required to have approved Management Plan and Forest Working Plan following the Planning Guide/ Manual by Sawarkar (2002) and the National Working Plan Code (MoEF, 2014), respectively. These management plans and forest working plans are also required to be revised usually every 10 years. In case of TRs, Tiger Conservation Plans (TCPs) are required to be prepared for legally designated 'Core' and 'Buffer' zones besides an indicative plan for connecting/ corridor areas linking TR with another TR or any other PA, following the guidelines issued by NTCA in 2007. These plans incorporate valuable information on diversity of forest/ vegetation types in the respective PA/ FD/ TR along with details on species composition and phytosociological insight based on adequate sampling and field level assessments throughout the reserve. Most plans also incorporate vegetation / forest cover map, details on changes in land use and land cover over a period, and regeneration status of prominent ecological and socioeconomic FGR species. Hence, the longish section on forest/ vegetation in each plan is an important repository of valuable information on floristics, phytosociology, etc. and this section serves as the foundation for management prescriptions towards species and habitat conservation. Hence, information on vegetation from plans can be an important source to understand the management effectiveness of FGR species. In addition, FSI has started providing information on forest cover and decadal changes in case of TRs from ISFR-2021 (FSI, 2021). Further, National/ State level scientific organizations *viz.*, WII, FRI, GBPIHESD, etc. and various universities undertake studies on floristics, especially phytosociological aspects and contribute valuable insight on vegetation structure, composition, and dynamics. The Nanda Devi BR including Nanda Devi NP, Valley of Flowers NP, and varied FDs as part of buffer zone have attracted long-term botanical research and vegetation monitoring activities. Likewise, other PAs are also receiving similar inputs but on a varying scale. The existing information on vegetation in PAs, FDs and TRs is widely scattered and often different documents lack consistency and uniformity in presentation style resulting into constraint in comparative analysis as well as developing insight on long-term trends. It was neither in the scope of the sub-component nor feasible to provide synthesized information on vegetation/ phytosociology for different PAs based on secondary information in view of the inconsistent datasets and wider gaps. However, the valuable information provided by ISFR, 2021 on the extent of Forest Type Groups in two TRs of Uttarakhand has been extracted and presented in the Chapter.

14.5.2

Occurrence of Prioritized FGR Species in PAs

The Chapter 5 has elaborated on the ecogeographic mapping of 50 prioritized FGR species, adopting MaxEnt Modeling based on 19 bioclimatic variables besides parameters like altitude, aspect, slope, direct normal irradiance, vapour, wind, land use and land cover, and soil, and field level surveys across different FDs and PAs. Some of the important outputs of this elaborate mapping study yielded insight on distribution of species across the altitudinal range, forest sub-types, estimated range, representation of geographical area of the State, forest cover, and occurrence in the PA. These results, except the per cent occurrence of prioritized FGR species in PAs of the State were well elaborated in the Chapter 5 itself. Considering the significance and relevance of the present Chapter, the research findings pertaining to percentage occurrence of FGR species in PAs were specifically computed by overlaying the potential/ predicted species distribution range over the RS and GIS based layer on PAs in the State and have been incorporated in the Chapter to illustrate the management.

14.5.3

Phytosociological Studies in Select PAs

Plant diversity in wild has more significance as species have diverse genotypes allowing adaptive capacity and evolutionary potential besides opportunities for commercial plantations in future. Changes in vegetation over a time is an imminent phenomenon, though, it is a long and steady process. Environment plays an important role in changes in the pattern of vegetation of an ecosystem (Billings, 1952). However, owing to burgeoning population and rapid industrialization, process of vegetation change has accelerated several folds. Forests are the storehouse of plant diversity; therefore, it is essential to assess and conserve plant diversity in forest areas. Hence, regular field level inventories, assessments and monitoring are essentially required for a proper understanding of phyto-diversity. The phytosociological study provides details and aptly predicts future patterns of vegetation (Mandal and Joshi, 2014). Therefore, for proper understanding of plant diversity of an area, phytosociological aspects need to be studied.

Out of 17 PAs in Uttarakhand, phytosociological studies were carried out in three PAs *viz.*, Rajaji TR, Nandhaur WLS, and Mussoorie WLS. In case of Rajaji TR, vegetation composition along with phytosociological aspects was assessed in two prominent Forest Type Groups *viz.*, Tropical Moist Deciduous Forest and Tropical Dry Deciduous Forest. In case of Nandhaur WLS, plant diversity was assessed in the Tropical Dry Deciduous Forest, whereas in case of Mussoorie WLS, phytosociological studies were carried out in the Himalayan Moist Temperate Forest. Number of Quadrats and the size were determined by the running men method (Kershaw, 1973) and species-area curve method (Misra, 1968). Quantitative analysis of vegetation for frequency, density and dominance was carried out following Misra (1968). Values of relative frequency, density and dominance were summed up to compute values of the Important Value Index (IVI). Quadrat size of 10 m x 10 m and 3 m x 3 m was adopted for trees and shrubs, respectively. Fifty quadrats were laid out randomly at each sampling site. In each quadrat, GBH (Girth at breast height at 1.37 m above ground level) in case of each tree was measured and recorded individually. For each Forest Type Group, following biodiversity indices were estimated:

Species Richness Index was estimated following Magralef (1958).

$$\mathbf{Dmg = S\text{-}1/\ln N}$$

Where S is the total number of species, and N is the total number of individuals.

Shannon Diversity Index (Shannon and Wiener, 1963) was calculated using the following formula:

$$\mathbf{H = -\sum p_i \ln p_i}$$

Where $p_i = (N_i/ N)$, N_i = Number of individuals of species i, and N = Total number of individuals of all the species.

Concentration of dominance (cd) was measured by Simpson Index (Simpson, 1949).

$$\mathbf{Cd = \sum (p_i)^2}$$

Pielou's Evenness Index was calculated using the following formula (Pielou, 1966):

$E = H' / \ln(S)$

Where 'H'' is Shannon Diversity Index and 'S' is the total number of species.

Thus, different diversity indices *viz.*, IVI, Shannon Diversity, Evenness Index, Concentration of dominance of tree and shrub layers were determined to capture the status of plant diversity for conservation and sustainable utilization.

14.6

Key Findings

Key findings based on the review of secondary information, MaxEnt Model based potential mapping and localized ecogeographic distribution of prioritized FGR species, extent of forest cover in different forest types within two TRs, and phytosociological assessment in three select PAs are summarized below one by one from the perspective of management effectiveness of conservation efforts of FGR in PAs of Uttarakhand.

14.6.1

Representation of Potential Ecogeographic Distribution Area in PAs

The findings based on the MaxEnt Modeling for potential ecogeographic distribution of 37 prioritized FGR species within PAs of Uttarakhand are presented in Table 14.2 and key findings are highlighted below.

Out of 37 species, only 35 FGR species showed potential ecogeographic distribution in PAs. Two species *viz.*, *Olea europaea* and *Premna mollisima* have shown no predictive distribution within PAs. The values of estimated ecogeographic distribution area in case of 35 species ranged from as low as 2.10 km^2 to 283.59 km^2 in case of *Diploknema butyracea* and *Betula utilis*, respectively (Table 14.2). In addition to lowest value in case of *D. butyracea*, ten FGR species *viz.*, *Alnus nepalensis, Buchanania cochinchinensis, Cinammomum tamala, Cornus capitata, Ficus neriifolia, Myrica esculenta, Prunus cerasoides, Quercus glauca, Quercus lanata* and *Tsuga dumosa* obtained values of estimated ecogeographic distribution area lower than 25 km^2 i.e., 13.76 km^2, 15.65 km^2, 13.42 km^2, 15.61 km^2, 12.59 km^2, 3.58 km^2, 17.56 km^2, 9.12 km^2, and 11.29 km^2, respectively (Table 14.2). In terms of percentage representation of ecogeographic distribution area within PAs in the context of 37 studied FGR species, the lowest value of 0.75 per cent was registered in case of *M. esculenta*, while the highest value of 92.93 per cent was estimated in case of *B. utilis*. Both these species are ecologically and economically important. The former FGR species is devoid of its potential ecogeographic distribution within PAs, while the latter appears to have its disproportionate distribution mainly restricted within PAs (Table 14.2). Distinctly, species like *Abies spectabilis, Acer caesium, Albizia julibrissin, Bombax ceiba, Corylus jacquemontii, Hovenia dulcis, Hymenodictyon orixense, Stereospermum chelonoides, Tsuga dumosa*, and *Ulmus wallichiana* obtained higher values of their potential ecogeographic distribution within PAs *viz.*, 57.9%, 33.7%, 30.38%, 33.53%, 45.74%, 43.57%, 37.61%, 69.16%, 72.66%, and 99.96%, respectively (Table 14.2). Amongst five prioritized FGR species selected for biochemical, molecular, and pathological characterization, *M. esculenta* with 0.75 per cent representation within PAs registered the lowest value, while *B. utilis* obtained the highest value of 92.93 per cent representation within PAs in terms of its potential ecogeographic distribution. Remaining three species *viz.*, *Quercus semecarpifolia, Taxus wallichiana*, and *Rhododendron arboreum* obtained values of ecogeographic distribution within PAs *viz.*, 21.99%, 27.67%, and 14.9%, respectively (Table 14.2). Species registering lower extent of their distribution range within PAs deserve higher attention as they are predominantly distributed outside PAs. Monitoring of such species is critical.

Table 14.2 Representation of Ecogeographic Distribution of Prioritized FGR Species in PAs of Uttarakhand

Sr. No.	Species	Altitudinal Range (m)	Estimated Ecogeographic Area (km^2)	Estimated Ecogeographic Area within PAs (km^2)	Representation of Ecogeographic Area in PAs (%)
1.	*Abies spectabilis*	2,712-3,684	147.85	85.61	57.90
2.	*Acer caesium*	2,288-3,653	183.97	62.00	33.70
3.	*Albizia julibrissin*	1,131-2,295	78.98	23.99	30.38
4.	*Alnus nepalensis*	1,227-3,044	143.65	13.76	9.58
5.	*Betula utilis*	2,817-3,806	305.16	283.59	92.93
6.	*Bombax ceiba*	203-1,865	716.9	240.38	33.53
7.	*Buchanania cochinchinensis*	207-1,690	146	15.65	10.72

Sr. No.	Species	Altitudinal Range (m)	Estimated Ecogeographic Area (km²)	Estimated Ecogeographic Area within PAs (km²)	Representation of Ecogeographic Area in PAs (%)
8.	*Buxus wallichiana*	2,141-2,646	187.57	48.09	25.64
9.	*Carpinus viminea*	1,646-2,471	174.26	42.62	24.46
10.	*Cinnamomum tamala*	886-2,619	158.62	13.42	8.46
11.	*Cornus capitata*	1,636-2,118	146.28	15.61	10.67
12.	*Corylus jacquemontii*	2,142-3,423	76.83	35.14	45.74
13.	*Diploknema butyracea*	509-1,526	200.10	2.10	1.05
14.	*Ficus neriifolia*	662-2,371	218.25	12.59	5.77
15.	*Fraxinus micrantha*	1,246-2,622	198.47	37.55	18.92
16.	*Hovenia dulcis*	1,218-2,174	77.1	33.59	43.57
17.	*Hymenodictyon orixense*	223-1,207	249.83	93.96	37.61
18.	*Juglans regia*	1,275-2,987	204.34	32.45	15.88
19.	*Myrica esculenta*	896-2,289	477.26	3.58	0.75
20.	*Olea europaea*	1,322-1,906	56.79	0.00	
21.	*Oroxylum indicum*	207-1,690	286.51	40.63	14.18
22.	*Ougeinia oojeinensis*	307-1,735	384.73	56.44	14.67
23.	*Phanera retusa*	364-2,105	191.94	25.14	13.10
24.	*Populus ciliata*	879-3,234	237.27	58.18	24.52
25.	*Premna mollissima*	346-1,738	161.38	0.00	
26.	*Prunus cerasoides*	1,320-2,954	185.99	5.38	2.89
27.	*Pterospermum acerifolium*	329-1,076	217.55	54.82	25.20
28.	*Quercus glauca*	842-2,205	184.26	17.56	9.53
29.	*Quercus lanata*	1,526-2,454	169.84	9.12	5.37
30.	*Quercus semecarpifolia*	2,249-3,652	832.4	183.04	21.99
31.	*Rhododendron arboreum*	1,145-3,312	617.48	92.00	14.90
32.	*Semecarpus anacardium*	210-1,447	227.91	56.48	24.78
33.	*Stereospermum chelonoides*	223-530	147.23	101.82	69.16
34.	*Taxus wallichiana*	2,192-3,432	545.86	151.04	27.67
35.	*Terminalia chebula*	222-1,602	262.89	60.36	22.96
36.	*Tsuga dumosa*	2,630-3,367	15.54	11.29	72.66
37.	*Ulmus wallichiana*	1,585-2,471	33.49	33.48	99.96

14.6.2

Localized Ecogeographic Distribution of Thirteen FGR Species within PAs

In case of 13 FGR species, the localized ecogeographic distribution estimated within PAs revealed that as many as six species have not shown any estimated distribution within PAs of Uttarakhand. These species were: *Carallia brachiate, Cochlospermum religiosum, Diospyros montana, Elaeodendron glaucum, Flacourtia jangomas*, and *Juniperus polycarpos*. Species like *Boswellia serrata* has bulk of its estimated localized ecogeographic distribution i.e., 99.75 per cent within PAs (Table 14.3). Species like *Madhuca longifolia* having enormous socioeconomic importance in terms of its fodder value and flowers being used in brewing local liquor besides medicinal value registered a lower extent of just 29.75 per cent of its estimated localized ecogeographic distribution within PAs (Table 14.3).

Table 14.3 Localised Ecogeographic Distribution of Prioritized FGR Species within Pas

Sr. No.	Species	Altitude (m)	Total Occurrence Area (km^2)	Estimated Ecogeographic Area within PAs (km^2)	Representation of Ecogeographic Area in PAs (%)
1.	*Albizia odoratissima*	286-1,787	24.14	3.14	13.01
2.	*Boswellia serrata*	297-415	9.42	9.40	99.75
3.	*Carallia brachiata*	222-542	7	-	-
4.	*Cochlospermum religiosum*	430	3.14	-	-
5.	*Diospyros montana*	556-828	9.42	-	-
6.	*Elaeodendron glaucum*	566-1,390	26.95	-	-
7.	*Flacourtia jangomas*	236-1,659	18.01	-	-
8.	*Juniperus polycarpos*	2,516	3.85	-	-
9.	*Litsea glutinosa*	396-609	14.5	3.42	23.59
10.	*Machilus gamblei*	562-975	9.7	2.23	22.99
11.	*Madhuca longifolia*	228-1,318	21.04	6.26	29.75
12.	*Pittosporum napaulense*	530-1,236	13.32	-	-
13.	*Trema orientalis*	350-2,068	32.13	10.32	32.13

14.6.3

Phytosociological Studies in Select PAs

As stated earlier, vegetation analysis for tree and shrub layers was carried out in three PAs. Key findings are presented below.

14.6.3.1

Rajaji Tiger Reserve

Findings on phytosociological analysis carried out for tree and shrub layers are described below:

Tree Diversity: In case of Rajaji TR, vegetation assessment was carried out in two prominent forest type groups viz., Tropical Dry Deciduous Forest and Tropical Moist Deciduous Forest. The analysis for tree layer revealed that the former and latter forest type groups registered 54 and 58 tree species, respectively (Table 14.4). Thirty-two tree species were common to both the forest type groups, while eighteen species were unique to the Tropical Dry Deciduous Forest and twenty-two species were unique to the Tropical Moist Deciduous Forest (Table 14.4). The comparison of two sampled forest type groups in RTR revealed that the overall tree density was higher in case of Tropical Dry Deciduous Forest, being 833.33 T ha^{-1} than the computed density of 790 T ha^{-1} in the Tropical Moist Deciduous Forest. There was a marginal difference in the overall values of total basal area (TBA) (Table 14.4).

In case of Tropical Dry Deciduous Forest, overall tree density (T ha^{-1}) of 833.33 was recorded in the sampled site within Rajaji TR, with highest density of *Ziziphus mauritiana* (106.67 T ha^{-1}), followed by *Anogeissus latifolia* (73.33 T ha^{-1}), and *Holoptelea integrifolia* (66.67 T ha^{-1}). The most frequently occurred species were *Z. mauritiana* and *A. latifolia* with the highest frequency value of 30 per cent in each case. Based on Important Value Index (IVI), *A. latifolia* (23.19) was the most dominant species in the Dry Deciduous Forest, followed by *Z. mauritiana* (21.74) and *H. integrifolia* (18.78). The minimum value of IVI, being 1.32 was recorded in case of *Bauhinia purpurea* (Table 14.4).

The findings based on vegetation analysis in the context of tree layer within the Tropical Moist Deciduous Forest are presented in Table 14.4. The tree layer was represented by 58 species obtaining an overall tree density value of 790 T ha^{-1}. Maximum value of tree density was estimated for *Shorea robusta* (176.67 T ha^{-1}), followed by *Ziziphus mauritiana* (53.33 T ha^{-1}), *Terminalia tomentosa* (50.00 T ha^{-1}), and *Mallotus philippensis* (43.33 T ha^{-1}), while minimum value of 3.33 T ha^{-1} was recorded in the case of *Flacourtia indica* (Table 14.4). Highest value of frequency of occurrence was obtained for *S. robusta* (70 per cent), followed by *T. tomentosa*, *Syzygium cumini*, *M. philippensis* and *Cordia dichotoma* registering 23.3 per cent in each case (Table 14.4). *S. robusta* was the most dominant species in the forest with highest value of IVI, being 67.42, followed by *T. tomentosa* (19.69), *S. cumini* (15.78), *M. philippensis* (13.67), and *C. dichotoma* (11.10), while the lowest value of IVI being 1.14 was obtained in case of *Flacourtia indica* (Table 14.4).

Table 14.4 - Quantitative Analysis of Tree Layer in Tropical Dry Deciduous and Tropical Moist Deciduous Forests of Rajaji Tiger Reserve

Sr. No.	Species	Tropical Dry Deciduous Forests				Tropical Moist Deciduous Forests			
		Density (T ha⁻¹)	Frequency (%)	TBA (m² ha⁻¹)	IVI	Density (T ha⁻¹)	Frequency (%)	TBA (m² ha⁻¹)	IVI
1.	*Acacia catechu*	63.33	26.7	5.27	18.32	23.33	13.33	2.15	7.51
2.	*Aegle marmelos*	6.67	3.3	0.69	2.17	3.33	3.33	0.39	1.43
3.	*Albizia lebbeck*	6.67	6.7	1.19	3.36	6.67	6.67	1.37	3.38
4.	*Albizia procera*	3.33	3.3	0.57	1.66	6.67	6.67	1.31	3.33
5.	*Alstonia scholaris*	-	-	-	-	3.33	3.33	0.70	1.70
6.	*Anogeissus latifolia*	73.33	30.0	8.51	23.19	6.67	3.33	0.81	2.22
7.	*Azadirachta indica*	3.33	3.3	0.41	1.51	-	-	-	-
8.	*Bauhinia purpurea*	3.33	3.3	0.20	1.32	-	-	-	-
9.	*Bauhinia racemosa*	16.67	10.0	0.32	4.53	3.33	3.33	0.18	1.25
10.	*Bauhinia retusa*	-	-	-	-	10.00	6.67	1.28	3.73
11.	*Bischofia javanica*	-	-	-	-	6.67	6.67	0.94	3.00
12.	*Bombax ceiba*	3.33	3.3	1.24	2.26	6.67	6.67	1.67	3.65
13.	*Boswellia serrata*	30.00	16.7	5.47	12.26	-	-	-	-
14.	*Bridelia retusa*	6.67	6.7	0.97	3.17	3.33	3.33	0.32	1.37
15.	*Buchanania cochinchinensis*	20.00	10.0	3.15	7.48	10.00	6.67	1.36	3.80
16.	*Butea monosperma*	10.00	10.0	0.97	4.31	10.00	10.00	1.71	4.77
17.	*Careya arborea*	-	-	-	-	13.33	10.00	1.76	5.24
18.	*Casearia tomentosa*	-	-	-	-	10.00	10.00	1.21	4.34
19.	*Cassia fistula*	10.00	6.7	0.80	3.41	6.67	6.67	0.78	2.86
20.	*Catunaregam spinosa*	6.67	3.3	0.20	1.73	3.33	3.33	0.18	1.25
21.	*Cochlospermum religiosum*	6.67	6.7	0.72	2.94	-	-	-	-
22.	*Cordia dichotoma*	3.33	3.3	0.20	1.33	30.00	23.33	2.99	11.10
23.	*Crateva adansonii*	16.67	6.7	0.91	4.31	-	-	-	-
24.	*Dalbergia lanceolaria*	6.67	6.7	0.54	2.78	-	-	-	-
25.	*Diospyros montana*	3.33	3.3	0.28	1.40	-	-	-	-
26.	*Ehretia laevis*	10.00	6.7	0.38	3.04	20.00	13.33	1.90	6.88
27.	*Elaeodendron glaucum*	-	-	-	-	3.33	3.33	0.18	1.25
28.	*Ficus benghalensis*	6.67	6.7	12.07	13.17	-	-	-	-
29.	*Ficus racemosa*	6.67	6.7	3.10	5.09	3.33	3.33	0.74	1.74
30.	*Ficus religiosa*	3.33	3.3	0.54	1.63	3.33	3.33	0.51	1.54
31.	*Ficus rumphii*	3.33	3.3	0.59	1.68	-	-	-	-
32.	*Ficus semicordata*	3.33	3.3	0.24	1.37	-	-	-	-
33.	*Flacourtia indica*	-	-	-	-	3.33	3.33	0.06	1.14
34.	*Garuga pinnata*	13.33	6.7	2.57	5.41	3.33	3.33	0.54	1.56
35.	*Glochidion ellipticum*	-	-	-	-	6.67	3.33	0.68	2.11
36.	*Haldina cordifolia*	13.33	10.0	3.22	6.74	6.67	6.67	1.68	3.66
37.	*Holarrhena pubescens*	6.67	6.7	0.39	2.64	20.00	13.33	1.56	6.57
38.	*Holoptelea integrifolia*	66.67	23.3	6.16	18.78	6.67	6.67	0.64	2.74
39.	*Hymenodictyon orixense*	10.00	6.7	7.02	9.02	-	-	-	-
40.	*Kydia calycina*	-	-	-	-	3.33	3.33	0.41	1.45
41.	*Lagerstroemia parviflora*	3.33	3.3	0.53	1.62	6.67	6.67	1.02	3.08
42.	*Lannea coromandelica*	6.67	6.7	1.05	3.24	-	-	-	-
43.	*Litsea glutinosa*	6.67	3.3	0.30	1.82	13.33	10.00	1.40	4.92
44.	*Litsea monopetala*	-	-	-	-	6.67	6.67	0.84	2.92

Sr. No.	Species	Tropical Dry Deciduous Forests				Tropical Moist Deciduous Forests			
		Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI	Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI
45.	*Machilus gamblei*	-	-	-	-	10.00	6.67	0.76	3.27
46.	*Madhuca longifolia var. latifolia*	40.00	20.0	8.19	16.66	3.33	3.33	0.79	1.78
47.	*Mallotus nudiflorus*	10.00	6.7	0.79	3.40	6.67	6.67	0.94	3.01
48.	*Mallotus philippensis*	30.00	10.0	2.16	7.79	43.33	23.33	3.99	13.67
49.	*Melia azedarach*	-	-	-	-	3.33	3.33	0.57	1.59
50.	*Miliusa velutina*	-	-	-	-	13.33	10.00	3.03	6.36
51.	*Mitragyna parviflora*	13.33	6.7	2.07	4.95	10.00	10.00	2.42	5.40
52.	*Naringi crenulata*	-	-	-	-	3.33	3.33	0.10	1.18
53.	*Nyctanthes arbor-tristis*	6.67	6.7	0.56	2.80	-	-	-	-
54.	*Oroxylum indicum*	-	-	-	-	3.33	3.33	0.17	1.24
55.	*Ougeinia oojeinensis*	6.67	6.7	0.87	3.07	3.33	3.33	0.42	1.46
56.	*Phoebe lanceolata*	-	-	-	-	6.67	6.67	0.34	2.47
57.	*Phyllanthus emblica*	6.67	6.7	1.00	3.20	6.67	6.67	0.52	2.64
58.	*Pinus roxburghii*	10.00	3.3	1.39	3.20	-	-	-	-
59.	*Schleichera oleosa*	6.67	6.7	0.95	3.15	26.67	13.33	4.02	9.59
60.	*Semecarpus anacardium*	-	-	-	-	6.67	3.33	0.08	1.58
61.	*Shorea robusta*	26.67	10.0	4.89	9.85	176.67	70.00	35.22	67.42
62.	*Sterculia villosa*	3.33	3.3	0.40	1.50	-	-	-	-
63.	*Stereospermum chelonoides*	10.00	10.0	1.14	4.46	6.67	6.67	1.09	3.14
64.	*Streblus asper*	-	-	-	-	3.33	3.33	0.42	1.46
65.	*Syzygium cumini*	6.67	6.7	1.16	3.34	33.33	23.33	7.82	15.78
66.	*Syzygium operculatum*	-	-	-	-	16.67	10.00	2.31	6.15
67.	*Terminalia bellerica*	6.67	6.7	1.13	3.31	6.67	6.67	1.36	3.37
68.	*Terminalia chebula*	3.33	3.3	1.30	2.31	-	-	-	-
69.	*Terminalia tomentosa*	33.33	13.3	6.07	12.46	50.00	23.33	9.86	19.69
70.	*Toona ciliata*	-	-	-	-	3.33	3.33	0.57	1.59
71.	*Triadica sebifera*	-	-	-	-	10.00	6.67	0.78	3.29
72.	*Vachellia eburnea*	16.67	10.0	0.62	4.80	-	-	-	-
73.	*Wrightia arborea*	23.33	10.0	2.82	7.58	3.33	3.33	0.21	1.27
74.	*Xylosma longifolia*	-	-	-	-	10.00	6.67	1.04	3.52
75.	*Ziziphus mauritiana*	106.67	30.0	2.46	21.74	53.33	13.33	1.32	10.58
76.	*Ziziphus xylopyrus*	6.67	3.3	0.23	1.75	-	-	-	-
	Total	833.33	-	110.96	-	790.00	-	113.38	-

Shrub Diversity: The vegetation assessment carried out for shrub layer of Rajaji Tiger Reserve in Tropical Dry Deciduous Forest and Tropical Moist Deciduous Forest registered the occurrence of 36 and 42 species, respectively (Table 14.5).

In Tropical Dry Deciduous Forest, the overall shrub density of 17,963 S ha^{-1} was recorded in the sampled site with the maximum density of *Justicia adhatoda* (2,000 S ha^{-1}), followed by *Lantana camara* (1,407 S ha^{-1}), and *Woodfordia fruticosa* (12,963 S ha^{-1}) while minimum value of 37.04 S ha^{-1} was recorded each in case of *Lagerstroemia parviflora* and *Celastrus paniculatus* (Table 14.5). Highest frequency of occurrence was estimated for *W. fruticosa* (53.00 per cent), followed by *Carissa opaca* (50 per cent), and 46.67 per cent in case of *Colebrookea oppositifolia* and *J. adhatoda* each (Table 14.5). Based on the values of IVI, *J. adhatoda* (31.57) was found to be the most dominant species, followed by *W. fruticosa* (22.18), *C. opaca* (21.78), and *C. oppositifolia* (20.98), while the minimum value of IVI was recorded for *Celastrus paniculatus* (0.80).

In the context of shrub layer within the Tropical Moist Deciduous Forest, the vegetation analysis revealed total density of 14,037 S ha^{-1} with the highest density recorded for *S. robusta* (1,703.7 S ha^{-1}), followed by *Clerodendrum infortunatum* (1,629.63 S ha^{-1}), and *Lantana camara* (1,111.11 S ha^{-1}) (Table 14.5). Most frequently occurred shrub species in the area were: *S. robusta* (56.67 per cent), *C. infortunatum* (46.67 per cent), and *L. camara* (40 per cent). On the basis of values of IVI, *S. robusta* (32.31) was estimated to be the most dominant species, followed by *C. infortunatum* (25.29), and *L. camara* (23.93), while *Dioscorea bellophylla* (0.93) recorded the least value for IVI (Table 14.5).

Table 14.5 - Quantitative Analysis of Shrub Layer in Tropical Dry Deciduous and Tropical Moist Deciduous Forests of Rajaji Tiger Reserve

Sr. No.	Species	Tropical Dry Deciduous Forests				Tropical Moist Deciduous Forests			
		Density (T ha^{-1})	Frequency (%)	TBA ($m^2\ ha^{-1}$)	IVI	Density (T ha^{-1})	Frequency (%)	TBA ($m^2\ ha^{-1}$)	IVI
1.	*Acacia catechu*	333.33	10.00	0.45	11.33	222.22	6.67	0.41	7.12
2.	*Aegle marmelos*	74.07	6.67	0.01	1.71	-	-	-	-
3.	*Albizia lebbek*	185.19	10.00	0.01	2.79	-	-	-	-
4.	*Anogeissus latifolia*	222.22	13.33	0.04	3.98	-	-	-	-
5.	*Ardisia solanacea*	-	-	-	-	333.33	10.00	0.23	6.60
6.	*Boswellia serrata*	296.30	10.00	0.10	4.97	-	-	-	-
7.	*Bridelia retusa*	-	-	-	-	74.07	6.67	0.09	2.63
8.	*Cajanus scabarioides*	148.15	10.00	0.08	3.79	-	-	-	-
9.	*Calamus tenuis*	-	-	-	-	148.15	3.33	0.10	2.69
10.	*Callicarpa macrophylla*	-	-	-	-	222.22	10.00	0.11	4.50
11.	*Carissa opaca*	888.89	50.00	0.52	21.78	444.44	10.00	0.25	7.60
12.	*Cassia fistula*	296.30	10.00	0.13	5.54	-	-	-	-
13.	*Catamixis baccharoides*	296.30	6.67	0.10	4.49	-	-	-	-
14.	*Celastrus paniculatus*	37.04	3.33	0.01	0.83	37.04	3.33	0.04	1.28
15.	*Clerodendrum infortunatum*	-	-	-	-	1629.63	46.67	0.50	25.29
16.	*Clerodendrum viscosum*	518.52	10.00	0.14	6.84	-	-	-	-
17.	*Colebrookea oppositifolia*	1111.11	46.67	0.43	20.98	-	-	-	-
18.	*Combretum roxburghii*	-	-	-	-	74.07	3.33	0.08	2.02
19.	*Cordia dichotoma*	-	-	-	-	333.33	13.33	0.24	7.31
20.	*Dioscorea belophylla*	-	-	-	-	37.04	3.33	0.01	0.93
21.	*Ehretia laevis*	111.11	10.00	0.04	2.89	-	-	-	-
22.	*Ficus hispida*	-	-	-	-	111.11	10.00	0.21	4.85
23.	*Ficus racemosa*	-	-	-	-	74.07	3.33	0.02	1.39
24.	*Flemingia chappar*	-	-	-	-	37.04	3.33	0.02	1.04
25.	*Flemingia macrophylla*	-	-	-	-	111.11	6.67	0.03	2.34
26.	*Grewia hirsuta*	555.56	23.33	0.07	7.88	-	-	-	-
27.	*Haldina cordifolia*	222.22	13.33	0.10	5.13	222.22	13.33	0.06	4.60
28.	*Helicteres isora*	370.37	16.67	0.15	7.19	333.33	20.00	0.40	10.17
29.	*Hiptage benghalensis*	-	-	-	-	74.07	3.33	0.12	2.36
30.	*Holarrhena pubescens*	370.37	16.67	0.05	5.60	-	-	-	-
31.	*Holoptelea integrifolia*	185.19	10.00	0.06	3.57	-	-	-	-
32.	*Ichnocarpus frutescens*	-	-	-	-	37.04	3.33	0.01	1.00
33.	*Ipomoea carnea*	-	-	-	-	148.15	3.33	0.10	2.67
34.	*Justicia adhatoda*	2000.00	46.67	0.75	31.57	925.93	30.00	0.44	16.62
35.	*Lagestromia parviflora*	37.04	3.33	0.03	1.24	-	-	-	-
36.	*Lantana camara*	1407.41	30.00	0.40	19.54	1111.11	40.00	0.84	23.93
37.	*Litsea glutinosa*	-	-	-	-	481.48	13.33	0.07	6.60

Sr. No.	Species	Tropical Dry Deciduous Forests				Tropical Moist Deciduous Forests			
		Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI	Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI
38.	*Maclura cochinchinensis*	-	-	-	-	222.22	6.67	0.35	6.45
39.	*Madhuca longifolia var. latifolia*	703.70	20.00	0.13	9.34	-	-	-	-
40.	*Mallotus philippensis*	592.59	20.00	0.21	10.09	555.56	23.33	0.61	14.60
41.	*Millettia extensa*	185.19	13.33	0.20	6.68	259.26	10.00	0.25	6.33
42.	*Mitragyna parviflora*	-	-	-	-	259.26	13.33	0.09	5.22
43.	*Murraya koenigii*	703.70	36.67	0.25	14.06	592.59	30.00	0.22	11.95
44.	*Olax nana*	185.19	6.67	0.02	2.48				
45.	*Oreocnide frurtescens*	-	-	-	-	407.41	13.33	0.26	8.09
46.	*Ougeinia oojeinensis*	74.07	6.67	0.04	2.22	-	-	-	-
47.	*Rubus niveus*	-	-	-	-	111.11	10.00	0.07	3.36
48.	*Schleichera oleosa*	-	-	-	-	259.26	13.33	0.53	9.90
49.	*Senna occidentalis*	370.37	13.33	0.07	5.43	-	-	-	-
50.	*Shorea robusta*	-	-	-	-	1703.70	56.67	0.95	32.31
51.	*Smilax ovalifolia*	-	-	-	-	37.04	3.33	0.03	1.18
52.	*Solanum torvum*	-	-	-	-	481.48	30.00	0.89	18.26
53.	*Syzygium cumini*	925.93	23.33	0.11	10.73	592.59	20.00	0.25	10.49
54.	*Tephrosia candida*	-	-	-	-	111.11	3.33	0.07	2.16
55.	*Vachellia eburnea*	296.30	10.00	0.09	4.76	-	-	-	-
56.	*Vallaris solanacea*	444.44	23.33	0.18	9.34	185.19	6.67	0.08	3.33
57.	*Vitex negundo*	1074.07	16.67	0.17	11.52	370.37	16.67	0.05	6.13
58.	*Woodfordia fruticosa*	1296.30	53.33	0.38	22.18	-	-	-	-
59.	*Xylosma longifolia*	-	-	-	-	111.11	6.67	0.04	2.44
60.	*Zanthoxylum armatum*	-	-	-	-	148.15	6.67	0.18	4.11
61.	*Ziziphus mauritiana*	1111.11	26.67	0.12	12.44	259.26	13.33	0.08	5.03
62.	*Ziziphus oenopolia*	185.19	10.00	0.03	3.09	148.15	10.00	0.03	3.11
63.	*Ziziphus xylopyrus*	148.15	6.67	0.01	2.01	-	-	-	-
	Total	**17,962.9**	-	**5.72**	-	**14,037.02**	-	**9.41**	-

14.6.3.2

Nandhaur Wildlife Sanctuary

Tree Diversity: The vegetation analysis of tree layer in Tropical Dry Deciduous Forest of Nandhaur Wildlife Sanctuary revealed total density of 268 T ha^{-1} and was represented by 49 species (Table 14.6). The highest density was recorded for *Shorea robusta* (22 T ha^{-1}), followed by *Holoptelea integrifolia* (18 T ha^{-1}), and *Schleichera oleosa* (16 T ha^{-1}), while *Debregeasia longifolia* (02 T ha^{-1}) showed the minimum density. The most frequently occurred species was *S. robusta* with the highest frequency value of 14 per cent (Table 14.6). The most dominant species with highest value for IVI was *S. robusta* (29.02), followed by *Ficus microcarpa* (25.99), and *S. oleosa* (19.06). The minimum value of IVI, being 1.65 was recorded in case of *Debregeasia longifolia* (Table 14.6).

Table 14.6 Vegetation Analysis of Tree Layer in Tropical Dry Deciduous Forest of Nandhaur Wildlife Sanctuary

Sr. No.	Species	Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI
1.	*Acacia catechu*	6	6	0.21	5.41
2.	*Aegle marmelos*	2	2	0.09	1.87
3.	*Albizia lebbeck*	2	2	0.15	2.06
4.	*Albizia odoratissima*	2	2	0.12	1.96
5.	*Albizia procera*	4	4	0.41	4.42
6.	*Alstonia scholaris*	2	2	0.24	2.30
7.	*Anogeissus latifolia*	6	4	0.36	5.00

Sr. No.	Species	Density (T ha^{-1})	Frequency (%)	TBA (m^2 ha^{-1})	IVI
8.	*Bauhinia racemosa*	8	8	0.19	6.96
9.	*Bischofia javanica*	4	4	0.12	3.57
10.	*Bridelia retusa*	4	4	0.09	3.48
11.	*Cassia fistula*	8	6	0.30	6.42
12.	*Cocculus laurifolius*	2	2	0.03	1.69
13.	*Cordia dichotoma*	2	2	0.03	1.69
14.	*Debregeasia longifolia*	2	2	0.02	1.65
15.	*Ehretia laevis*	2	2	0.07	1.80
16.	*Ficus microcarpa*	4	4	7.74	25.99
17.	*Ficus racemosa*	4	4	0.84	5.67
18.	*Ficus rumphii*	2	2	0.12	1.95
19.	*Ficus semicordata*	8	8	0.21	7.01
20.	*Ficus virens*	2	2	1.66	6.48
21.	*Firmiana fulgens*	2	2	0.14	2.01
22.	*Garuga pinnata*	4	4	0.29	4.05
23.	*Haldina cordifolia*	4	4	1.13	6.53
24.	*Heynea trijuga*	4	6	0.05	4.20
25.	*Holarrhena pubescens*	8	8	0.12	6.75
26.	*Holoptelea integrifolia*	18	10	1.17	14.43
27.	*Hymenodictyon orixense*	2	2	0.63	3.45
28.	*Lagestromia parviflora*	10	8	0.53	8.72
29.	*Lannea coromandelica*	8	6	0.79	7.88
30.	*Litsea monopetala*	6	2	0.30	3.98
31.	*Mallotus philippensis*	8	8	0.34	7.42
32.	*Mangifera indica*	2	2	0.61	3.40
33.	*Melia azedarach*	2	2	0.33	2.56
34.	*Moringa oleifera*	2	4	0.72	4.59
35.	*Ougeinia oojeinensis*	4	4	0.20	3.78
36.	*Phoebe lanceolata*	4	4	0.10	3.48
37.	*Phoenix loureiroi*	2	2	0.05	1.74
38.	*Putranjiva roxburghii*	8	8	0.82	8.83
39.	*Pyrus pashia*	2	2	0.05	1.74
40.	*Salix tetrasperma*	6	4	0.06	4.12
41.	*Schleichera oleosa*	16	12	2.70	19.06
42.	*Shorea robusta*	22	14	5.04	29.02
43.	*Syzygium cumini*	10	10	2.03	13.99
44.	*Terminalia bellerica*	6	6	0.57	6.47
45.	*Terminalia chebula*	4	4	0.21	3.83
46.	*Terminalia tomentosa*	14	10	1.36	13.49
47.	*Toona ciliata*	6	6	0.54	6.38
48.	*Trema orientale*	6	6	0.06	4.97
49.	*Wendlandia heynei*	2	2	0.05	1.75
	Total	268	-	33.96	-

Shrub Diversity: The shrub layer of Dry Deciduous Forest of Nandhaur Wildlife Sanctuary was represented by 38 species with a total density of 2,177 S ha^{-1}. The highest density was estimated for *Clerodendrum infortunatum* (266.64 S ha^{-1}), followed by *Colebrookea oppositifolia* (199.98 S ha^{-1}), and *Lantana camara* (177.76 S ha^{-1}) (Table 14.7). On the basis of values of IVI, *S. robusta* was estimated to be the most dominant species in the area with highest value (25.35), followed by *C. infortunatum* (24.76), *Murraya koenigii* (19.76), and *C. oppositifolia* (19.67), while the minimum value of IVI, being 2.54 was recorded for *Asclepias curassavica* (Table 14.7).

Table 14.7 Vegetation Analysis of Shrub Layer in Tropical Dry Deciduous Forest of Nandhaur Wildlife Sanctuary

Sr. No.	Species	Density (S ha^{-1})	Frequency (%)	TBA ($m^2 ha^{-1}$)	IVI
1.	*Aegle marmelos*	22.22	2	0.006	2.67
2.	*Ampelocissus latifolia*	22.22	2	0.005	2.64
3.	*Asclepias curassavica*	22.22	2	0.003	2.54
4.	*Bauhinia racemosa*	44.44	4	0.038	6.83
5.	*Bombax ceiba*	44.44	2	0.095	8.72
6.	*Callicarpa arborea*	66.66	4	0.015	6.59
7.	*Cassia fistula*	66.66	6	0.116	13.58
8.	*Catunaregam spinosa*	44.44	4	0.121	11.54
9.	*Cissus repanda*	22.22	2	0.006	2.68
10.	*Clerodendrum infortunatum*	266.64	14	0.057	24.76
11.	*Colebrookea oppositifolia*	199.98	10	0.068	19.67
12.	*Cryptolepis buchananii*	22.22	2	0.004	2.56
13.	*Ficus hederacea*	66.66	4	0.014	6.53
14.	*Ficus semicordata*	66.66	6	0.128	14.25
15.	*Haldina cordifolia*	44.44	4	0.058	7.95
16.	*Holarrhena pubescens*	44.44	4	0.089	9.69
17.	*Ichnocarpus frutescens*	44.44	4	0.033	6.57
18.	*Justicia adhatoda*	88.88	2	0.010	5.98
19.	*Lagestromia parviflora*	44.44	4	0.050	7.55
20.	*Lantana camara*	177.76	6	0.033	14.02
21.	*Maesa indica*	22.22	2	0.007	2.75
22.	*Mallotus philippensis*	44.44	4	0.019	5.76
23.	*Mangifera indica*	22.22	2	0.044	4.83
24.	*Millettia extensa*	44.44	4	0.036	6.71
25.	*Murraya koenigii*	111.10	8	0.166	19.76
26.	*Phanera vahlii*	44.44	4	0.054	7.76
27.	*Phlogacanthus thyrsiformis*	44.44	2	0.008	3.85
28.	*Pueraria tuberosa*	44.44	4	0.032	6.50
29.	*Rubus ellipticus*	22.22	2	0.004	2.57
30.	*Salix tetrasperma*	22.22	2	0.008	2.80
31.	*Schleichera oleosa*	66.66	6	0.096	12.45
32.	*Shorea robusta*	133.32	10	0.223	25.35
33.	*Terminalia bellerica*	22.22	2	0.045	4.86
34.	*Terminalia chebula*	22.22	2	0.007	2.75
35.	*Trema orientale*	22.22	2	0.006	2.69
36.	*Ventilago denticulata*	22.22	2	0.029	3.98
37.	*Vitex negundo*	22.22	2	0.010	2.89
38.	*Wallichia oblongifolia*	22.22	2	0.036	4.41
	Total	2,177.56	-	1.776	-

14.6.3.3
Mussoorie Wildlife Sanctuary

Tree Diversity: On the basis of vegetation analysis, tree layer of the Himalayan Moist Temperate Forest of Mussoorie Wildlife Sanctuary was represented by 38 species with overall tree density of 428 T ha^{-1}. The highest density was recorded for *Cedrus deodara* (46 T ha^{-1}), followed by *Pinus roxburghii* (40 T ha^{-1}), and *Machilus duthiei* (36 T ha^{-1}). The most frequently occurred species in the area was *C. deodara* with the highest frequency of occurence (30 per cent), followed by 18 per cent each in case of *P. roxburghii* and *M. duthiei* (Table 14.8). *C. deodara* with the highest value of IVI (49.79) was recorded as the most dominant species, followed by *P. roxburghii* (34.29), and *M. duthiei* (19.76), while the minimum value of IVI, being 1.26 was recorded in case of both *Eurya acuminata* and *Buxus wallichiana* (Table 14.8).

Table 14.8 Vegetation Analysis of Tree Layer in the Himalayan Moist Temperate Forest of Mussoorie Wildlife Sanctuary

Sr. No.	Species	Density(T ha^{-1})	Frequency (%)	TBA(m^2 ha^{-1})	IVI
1.	*Acer oblongum*	26	16	1.50	15.78
2.	*Aesculus indica*	8	8	1.29	8.11
3.	*Betula alnoides*	4	4	0.40	3.44
4.	*Buxus wallichiana*	2	2	0.02	1.26
5.	*Cedrus deodara*	46	30	10.94	49.79
6.	*Celtis australis*	8	4	0.14	3.69
7.	*Cocculus laurifolius*	2	2	0.05	1.33
8.	*Coriaria napalensis*	20	16	0.29	11.31
9.	*Cornus capitata*	12	10	0.25	7.12
10.	*Cornus macrophylla*	6	6	0.83	5.74
11.	*Cornus oblonga*	16	12	0.79	10.17
12.	*Cupressus torulosa*	28	14	2.89	19.08
13.	*Daphniphyllum himalense*	34	6	2.39	16.26
14.	*Eurya acuminata*	2	2	0.02	1.26
15.	*Ficus auriculata*	4	4	0.05	2.53
16.	*Grewia oppositifolia*	10	6	0.28	5.26
17.	*Ilex pseudo-odorata*	6	2	0.44	3.27
18.	*Juglans regia*	4	4	0.55	3.81
19.	*Litsea umbrosa*	2	2	0.04	1.29
20.	*Lyonia ovalifolia*	6	6	0.18	4.08
21.	*Machilus duthiei*	36	18	1.85	19.76
22.	*Machilus odorratissima*	20	16	0.77	12.53
23.	*Myrica esculenta*	4	4	0.17	2.83
24.	*Ougeinia oojeinensis*	2	2	0.09	1.44
25.	*Pinus roxburghii*	40	18	7.16	34.29
26.	*Pinus wallichiana*	14	8	1.61	10.33
27.	*Populus ciliata*	2	2	0.50	2.48
28.	*Prunus cerasoides*	4	4	0.26	3.07
29.	*Pyrus pashia*	4	4	0.12	2.70
30.	*Quercus floribunda*	4	4	0.12	2.72
31.	*Quercus leucotrichophora*	24	12	2.28	15.86
32.	*Rhododendron arboreum*	6	4	0.10	3.12
33.	*Sapium insigne*	6	6	0.23	4.21
34.	*Toona sinensis*	2	2	0.12	1.52
35.	*Trachycarpus fortunei*	2	2	0.03	1.29
36.	*Viburnum coriaceum*	2	2	0.07	1.38
37.	*Viburnum cotinifolium*	6	4	0.19	3.36
38.	*Wendlandia heynei*	4	4	0.05	2.53
	Total	428	-	39.06	-

Shrub Diversity: The vegetation analysis of shrub layer of the Himalayan Moist Temperate Forest of Mussoorie Wildlife Sanctuary revealed 63 species with total density of 4,510 S ha^{-1}. Highest density was estimated for *Drepanostachyum falcatum* (311.08 S ha^{-1}), followed by 266.64 S ha^{-1} in case of both *Sarcococca saligna*, and *Berberis chitria* (Table 14.9). The highest frequency of occurrence was recorded for *B. chitria* (16 per cent), followed by 12 per cent each in case of *D. falcatum*, *Princepia utilis*, and *Machilus odoratissima*. The highest value of IVI was estimated for *D. falcatum* (13.39), followed by *B. chitria* (13.34), and *P utilis* (12.03), while the minimum value of IVI, being 1.27 was recorded for *Myrsine africana* (Table 14.9).

Table 14.9 Vegetation Analysis of Shrub Layer in the Himalayan Moist Temperate Forest of Mussoorie Wildlife Sanctuary

Sr. No.	Species	Density(T ha^{-1})	Frequency (%)	TBA(m^2 ha^{-1})	IVI
1.	*Acer oblongum*	111.1	6	0.261	11.06
2.	*Berberis asiatica*	88.88	8	0.018	5.28
3.	*Berberis chitria*	266.64	16	0.069	13.34
4.	*Buxus wallichiana*	22.22	2	0.004	1.31
5.	*Campylotropis macrostyla*	22.22	2	0.006	1.36
6.	*Carissa spinarum*	44.44	4	0.009	2.64
7.	*Cedrus deodara*	88.88	6	0.159	8.04
8.	*Clematis gouriana*	177.76	4	0.030	6.10
9.	*Clematis montana*	66.66	4	0.014	3.24
10.	*Colebrookea oppositifolia*	22.22	2	0.011	1.47
11.	*Coriaria napalensis*	44.44	4	0.068	4.09
12.	*Cornus capitata*	66.66	4	0.155	6.75
13.	*Cornus macrophylla*	66.66	4	0.148	6.56
14.	*Cornus oblonga*	44.44	2	0.048	2.88
15.	*Cotoneaster bacillaris*	44.44	4	0.045	3.53
16.	*Cupressus torulosa*	111.1	10	0.221	11.51
17.	*Daphne papyracea*	66.66	4	0.020	3.41
18.	*Daphniphyllum himalense*	111.1	10	0.214	11.32
19.	*Debregeasia longifolia*	44.44	4	0.103	4.97
20.	*Debregeasia saeneb*	22.22	2	0.021	1.73
21.	*Dioscorea deltoidea*	44.44	2	0.015	2.06
22.	*Drepanostachyum falcatum*	311.08	12	0.089	13.39
23.	*Ficus hederacea*	133.32	6	0.119	8.04
24.	*Flemingia bracteata*	44.44	4	0.011	2.68
25.	*Flemingia strobilifera*	22.22	2	0.010	1.46
26.	*Hedera nepalensis*	111.1	8	0.067	6.97
27.	*Himalrandia tetrasperma*	22.22	2	0.010	1.45
28.	*Indigofera heterantha*	88.88	4	0.030	4.13
29.	*Jasminum grandiflorum*	44.44	2	0.008	1.89
30.	*Lantana camara*	155.54	6	0.045	6.71
31.	*Lonicera quinquelocularis*	66.66	4	0.096	5.27
32.	*Machilus duthiei*	44.44	4	0.116	5.28
33.	*Machilus odorratissima*	133.32	12	0.132	10.52
34.	*Mahonia nepaulensis*	66.66	6	0.074	5.45
35.	*Myrica esculenta*	22.22	2	0.007	1.38
36.	*Myrisine semiserrata*	22.22	2	0.006	1.36
37.	*Myrsine africana*	22.22	2	0.003	1.27
38.	*Osyris lanceolata*	22.22	2	0.088	3.39
39.	*Phanera vahlii*	22.22	2	0.099	3.66
40.	*Pinus roxburghii*	88.88	4	0.186	8.01
41.	*Pinus wallichiana*	22.22	2	0.007	1.38
42.	*Prinsepia utilis*	177.76	12	0.154	12.03
43.	*Prunus cerasoides*	22.22	2	0.033	2.04
44.	*Pseudocaryopteris foetida*	22.22	2	0.008	1.40
45.	*Pyracantha crenulata*	44.44	2	0.035	2.57
46.	*Pyrus pashia*	22.22	2	0.006	1.34
47.	*Quercus leucotrichophora*	111.1	6	0.159	8.55
48.	*Rhododendron arboreum*	133.32	10	0.183	11.07
49.	*Rhus chinensis*	44.44	2	0.050	2.94
50.	*Rhus parviflora*	155.54	8	0.103	8.86

Sr. No.	Species	Density(T ha^{-1})	Frequency (%)	TBA(m^2 ha^{-1})	IVI
51.	*Rosa moschata*	44.44	4	0.008	2.61
52.	*Rubus ellipticus*	44.44	4	0.007	2.59
53.	*Rubus niveus*	44.44	2	0.009	1.93
54.	*Rubus paniculatus*	44.44	2	0.029	2.42
55.	*Sapium insigne*	44.44	2	0.134	5.00
56.	*Sarcococca saligna*	266.64	8	0.076	10.65
57.	*Toona sinensis*	22.22	2	0.003	1.28
58.	*Toxicodendron wallichii*	44.44	4	0.050	3.65
59.	*Vitex negundo*	22.22	2	0.010	1.45
60.	*Wendlandia heynei*	22.22	2	0.045	2.31
61.	*Wikstroemia canescens*	22.22	2	0.007	1.38
62.	*Woodfordia fruticosa*	66.66	4	0.055	4.26
63.	*Zanthoxylum armatum*	44.44	4	0.039	3.37
	Total	4,510.66	-	4.044	-

Diversity Indices: Diversity indices *viz.*, Species Richness (SR), Shannon Diversity Index (H), Concentration of Dominance (CD), and Evenness (E) are used to describe the general properties of communities which facilitate the comparison of different regions and taxa. Diversity Index (H), indicates variability in the types of species and heterogeneity in a community whereas CD signifies the homogenous nature of a community and such communities are dominated by few dominant species. Evenness (E) is a measure of how evenly a species is distributed in an area. The diversity indices for tree and shrub layers within select PAs of Uttarakhand is presented in Table 14.10 and summarized below.

Species Richness (SR): In tree layer, the Tropical Dry Deciduous Forest in Nandhaur WLS recorded the highest value for tree species richness (8.58); followed by Tropical Moist Deciduous Forest (8.54), and Tropical Dry Deciduous Forest (7.88) in Rajaji TR; and Himalayan Moist Temperate Forest (6.11) in Mussoorie WLS (Table 14.10).

In case of shrub layer, highest species richness was estimated for Moist Temperate Forest (7.37) in Mussoorie WLS, while species richness was found to be the lowest (3.57) in case of Tropical Dry Deciduous Forest in Rajaji TR (Table 14.10).

Diversity Index (H): In tree layer, maximum value for Diversity Index was estimated for the Tropical Dry Deciduous Forest (3.632) in Nandhaur WLS indicating higher variability in the type of species in this region, while the Himalayan Moist Temperate Forest in Mussoorie WLS recorded the minimum value (3.172) for diversity index (Table 14.10).

In case of shrub layer, the Himalayan Moist Temperate Forest in Belong WLS revealed higher heterogeneity with maximum value for H (3.84), while the minimum value for H (3.23) was obtained for the Tropical Dry Deciduous Forest in Rajaji TR (Table 14.10).

Concentration of Dominance (CD): In tree layer, the Tropical Moist Deciduous Forest in Rajaji TR obtained the highest value for CD (0.072), while the minimum value for CD (0.033) was recorded for Tropical Dry Deciduous Forest in Nandhaur WLS (Table 14.10).

In shrub layer, the Tropical Moist Deciduous Forest in Rajaji TR with maximum value for CD (0.054) was estimated to be the most homogenous, while the Himalayan Moist Temperate Forest in Mussoorie WLS with minimum CD (0.028) was found to be the least homogenous (Table 14.10).

Evenness (E): In tree layer, highest degree of evenness was reported for the Tropical Dry Deciduous Forest in Nandhaur WLS with maximum value for E (0.933), while minimum value for evenness (0.829) was recorded in case of the Tropical Moist Deciduous Forest of Rajaji TR (Table 14.10).

In shrub layer, the Himalayan Moist Temperate Forest from Mussoorie WLS was recorded to have maximum evenness (0.92), followed by the Tropical Dry Deciduous Forest from Nandhaur WLS (0.91). Whereas, the Tropical Moist Deciduous Forest from Rajaji TR recorded the minimum value for evenness (0.87) (Table 14.10).

Table 14.10 Diversity Indices for Different Growth Forms in Select Protected Areas of Uttarakhand

Protected Area	Forest Type	Tree Layer				Shrub Layer			
		SR	H	CD	E	SR	H	CD	E
Rajaji TR	Tropical Dry Deciduous Forest	7.88	3.45	0.05	0.87	3.57	3.23	0.05	0.90
	Tropical Moist Deciduous Forest	8.54	3.37	0.07	0.83	4.29	3.27	0.05	0.87
Nandhaur WLS	Tropical Dry Deciduous Forest	8.58	3.63	0.03	0.93	4.81	3.32	0.05	0.91
Mussoorie WLS	Himalayan Moist Temperate Forest	6.11	3.17	0.06	0.87	7.37	3.84	0.03	0.92

In the tree layer, based on different biodiversity attributes viz., species richness, diversity index, concentration of dominance and evenness, the Tropical Dry Deciduous Forest from Nandhaur WLS was found to be the most diverse, followed by Tropical Moist Deciduous Forest, and Tropical Dry Deciduous Forest in Rajaji TR; and the Himalayan Moist Temperate Forest from Mussoorie WLS. However, in shrub layer, highest diversity was estimated for the Himalayan Moist Temperate Forest, Mussoorie WLS, followed by Tropical Dry Deciduous Forest, Nandhaur WLS; and Tropical Moist Deciduous Forest, and Tropical Dry Deciduous Forest from Rajaji TR.

14.6.4

Change in Forest Cover and Diversity of Forest Types in Tiger Reserves of Uttarakhand

The following section based on ISFR-2021 by FSI (2021) describes the change in forest cover and diversity of forest types in two TRs of the State.

14.6.4.1

Change in Forest Cover

The State has two Tiger Reserves *viz.*, Corbett TR and Rajaji TR belonging to the Shiwalik Hills and Gangetic Plains ecological landscape defined in the context of tiger conservation in the country. The Corbett TR has notified Core zone of 821.99 km^2 and Buffer zone of 546.92 km^2, thus having total area of 1,368.91 km^2. The buffer area of CTR also extends in Amangarh Forest Range, Uttarpradesh. The Rajaji TR has notified area of core of 819.54 km^2, and buffer zone 255.63 km^2, and thus, with a total area of 1,075.17 km^2 (FSI, 2021). The ISFR- 2021 has included a full Chapter on the assessment of forest cover in Tiger Reserve areas of the country. Accordingly, the forest cover under three forest canopy density classes as per the 2011 and 2021 assessments along with the change in forest cover during the decadal period (2011-2021) are presented in Table 14.11. Notably, both TRs of Uttarakhand showed decline in forest cover by 29.91 km^2 (Corbett) and 30.20 km^2 (Rajaji) during the decadal period. As per ISFR-2021, Corbett TR registered 83.73 per cent of total Forest Cover with regard to area of digitized boundaries of TR, while Rajaji had 89 per cent of total Forest Cover w.r.t area of its digitized boundaries (Table 14.11). These two TRs of Uttarakhand were among 32 TRs of the country out of 52 TRs which registered decline in the total extent of forest cover in the decadal period of two corresponding assessments. However, both TRs distinctly showed a notable increase in their VDF area from 330.58 km^2 to 441.44 km^2 (Corbett TR), and from 188.65 km^2 to 258.38 km^2 (Rajaji TR) during the decadal period. This increase in VDF in both TRs was on account of decline in MDF and shift towards VDF category of forest cover. Although, both TRs of Uttarakhand have adopted a comprehensive and multifold approach towards protection and conservation of their precious forest and biological resources, they continue to face enormous pressure on account of resource dependance, growing urban centers, enhanced tourism activities, developmental activities, and proliferation of invasive and alien species, especially in the case of buffer zones of each TR. The overall decline of 1.57 per cent in forest cover of CTR and 2.73 per cent in RTR in a decadal period (2011-2021) corroborating further with dominance of invasive species like Lantana camara and other unpalatable shrub species as indicated above in section 14.6.3 reflects that from the perspective of management effectiveness of PAs as well as FGR species, decline in the extent of forest cover and quality of forests by way of proliferation of invasive species are important concerns (ISFR, 2021).

14.6.4.2

Diversity of Forest Types

Out of 16 major Forest Type Groups based on the revised Forest Type Classification by Champion and Seth (1968), the ISFR-2021 reported occurrence of four Forest Type Groups each in CTR and RTR. In case of Corbett TR, Group 3 - Tropical Moist Deciduous Forest was the dominant type and was represented by an extent of 994.43 km^2 forest cover. This was followed by 223.67 km^2 of Group 5 - Tropical Dry Deciduous Forest (Table 14.12). Two other forest type groups namely Group 9- Sub-Tropical Pine Forests and Group 12 - Himalayan Moist Temperate Forests covered an extent of 3.65 km^2 and 0.01 km^2 forest cover, respectively. Like Corbett TR, the Rajaji TR also had the maximum extent of forest cover, being 507.45 km^2 in case of Tropical Moist Deciduous Forest, followed by Tropical Dry Deciduous Forest represented by forest cover of 444.10 km^2. Sub- Tropical Pine Forest registered a small extent of forest cover of 1.76 km^2. Instead of the Himalayan Moist Temperate Forests in case of CTR, the RTR had a small extent (0.76 km^2) of Group 4 - Littoral and Swamp Forests (Table 14.12). Five different Forest Type Groups represented in two well protected TRs covering a cumulative extent of about 2,150 km^2 forest cover under three forest canopy density classes certainly harbour a wide array of FGR species. Hence, these two TRs besides other PAs significantly contribute not only towards conservation of floral and faunal diversity but also in the maintenance of genetic diversity within FGR species.

Table 14.11 - Change in Forest Cover of Corbett and Rajaji Tiger Reserves Between 2011 and 2021 Assessments by FSI

Tiger Reserve	Area as per Digitized Tiger Reserve Boundary	2011 Assessment							
		VDF	MDF	OF	Total Forest Cover	% of Total FC w.r.t Area of TR	Scrub	VDF	MDF
Corbett (Uttarakhand and Uttar Pradesh)	1,462.66	330.58	825.4	91.61	1,247.59	85.3	0	441.44	693.37
Rajaji (Uttarakhand)	1,102.41	188.65	631.2	191.44	1,011.29	91.73	0	253.38	563.49

Source: Extract from ISFR 2021 (FSI, 2021)

Table 14.12 - Diversity of Forest Types in Corbett and Rajaji Tiger Reserves of Uttarakhand

Sr. No.	Tiger Reserve	Forest Type Group						
		Group 1 Tropical Wet Evergreen Forest	Group 2 Tropical Semi-Evergreen Forest	Group 3 Tropical Moist Deciduous Forest	Group 4 Littoral and Swamp Forest	Group 5 Tropical Dry Deciduous Forest	Group 6 Tropical Thorn Forest	Group 8 Sub-Tropical Broad-Leaved Hill Forest
1.	Corbett (including Amangarh Buffer)	-	-	994.43	-	223.67	-	-
2.	Rajaji	-	-	507.45	0.76	444.1	-	-

Source: Extract from ISFR 2021 (FSI, 2021)

14.7

Key Messages and Future Prospects

Six prominent National Parks and seven Sanctuaries besides two TRs, one BR, one ER, two WHSs, and four CRs in a vast forested Himalayan State are important repository of tropical biodiversity including a wide array of FGR species and RET species. From the perspective of long-term conservation of FGR and the maintenance of their genetic diversity, PAs and above stated conservation areas have a major role to play. In most instances, these PAs and other conservation areas are adequately cushioned by buffer of managed forests and legally designated eco-sensitive zones. Corbett NP is in existence since 1936, while other five NPs established three to four decades ago or so continue to receive maximum protection under the Wildlife (Protection) Act, 1972 with no human use policy, except regulated tourism are important in situ conservation areas for the sustainability of biodiversity including FGR species, source of wide range of ecosystem services, and natural sites for ecological and evolutionary processes. The UKFD, the custodian of these conservation sites with its hierarchical network of forest frontline staff has made enormous contribution towards the establishment and management of living resources vital for healthy planet and human well-being. Although, these conservation areas face varied challenges including climate change and its implications, they remain the best insurance for long-term conservation of FGR. Thus, these conservation areas demand resolute support for their unhindered continuance and maintenance at all levels so they remain active centers for fulfilling global obligations and National/ State level commitments towards conservation of biodiversity, forest genetic resources, climate change mitigation and adaptation, sustainable livelihoods and development.

The predictive ecogeographic mapping in case of prioritized FGR species amply reflected that several FGR species have their substantial distribution outside PAs, mainly in managed forests or even *circa situm* conservation repositories in rural/ agricultural landscapes. Hence, it is essential that PAs, MFs and other conservation areas are considered together as interdependent entities in a wider landscape. The Ecosystem Based Forest Management (EBFM) or landscape approach to conservation is relevant in the case of Himalayan State.

With the advent of modern biological sciences, the traditional disciplines of forest botany, phytosociological studies, and allied aspects like population structure, regeneration status, species distribution and status are losing charm. Moreover, these field based surveys and studies in vast

2021 Assessment				Change in Forest Cover w.r.t ISFR 2011
OF	Total	% of Total FC w.r.t Area of TR	Scrub	
89.87	1,224.68	83.73	2.97	-22.91
164.22	981.09	89	2.36	-30.2

							Total
Group 9 Sub-Tropical Pine Forest	Group 11 Montane Wet Temperate Forest	Group 12 Himalayan Moist Temperate Forest	Group 14 Sub-Alpine Forest	Group 15 Moist Alpine Scrub	Group 16 Dry Alpine Scrub	TOF/ Plantation	
3.65	-	0.01	-	-	-	19.64	1241.4
1.76	-	-	-	-	-	31.1	985.08

Himalayan State are difficult, cumbersome and expensive besides the process is protracted one and needs to be repeated periodically. The review of literature amply indicated that the existing information on basic phytosociology, species distribution, population structure and regeneration status is either widely scattered that too in unpublished documents or piecemeal or even obsolete in several instances. This situation demands an urgent attention towards this important aspect, especially in the case of vast array of FGR species.

The perusal of change in forest cover in case of two TRs indicated slight decline in the decadal period besides decline in forest quality owing to proliferation of invasive and alien species, and poor regeneration of native species. Such decline in quantity and quality cannot be overlooked in view of the actual and potential use of FGR.

The government agencies, non-governmental organizations and communities collectively in the Himalayan State of Uttarakhand like other States/ UTs of the country have made notable contributions and sacrifices to conserve PAs and associated diversity of FGR. These efforts (management, research and monitoring) need to be strengthened and augmented.

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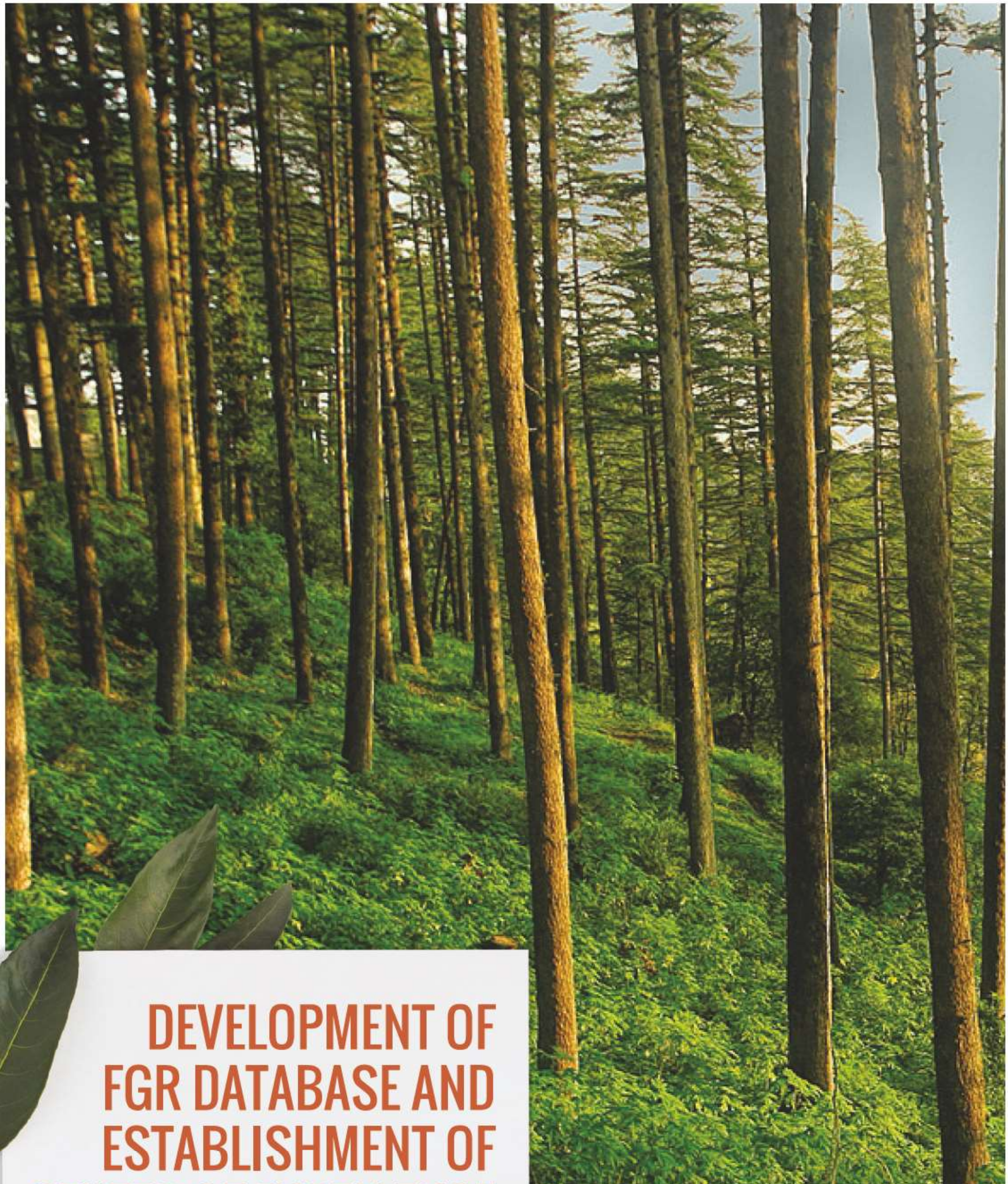
PART 06

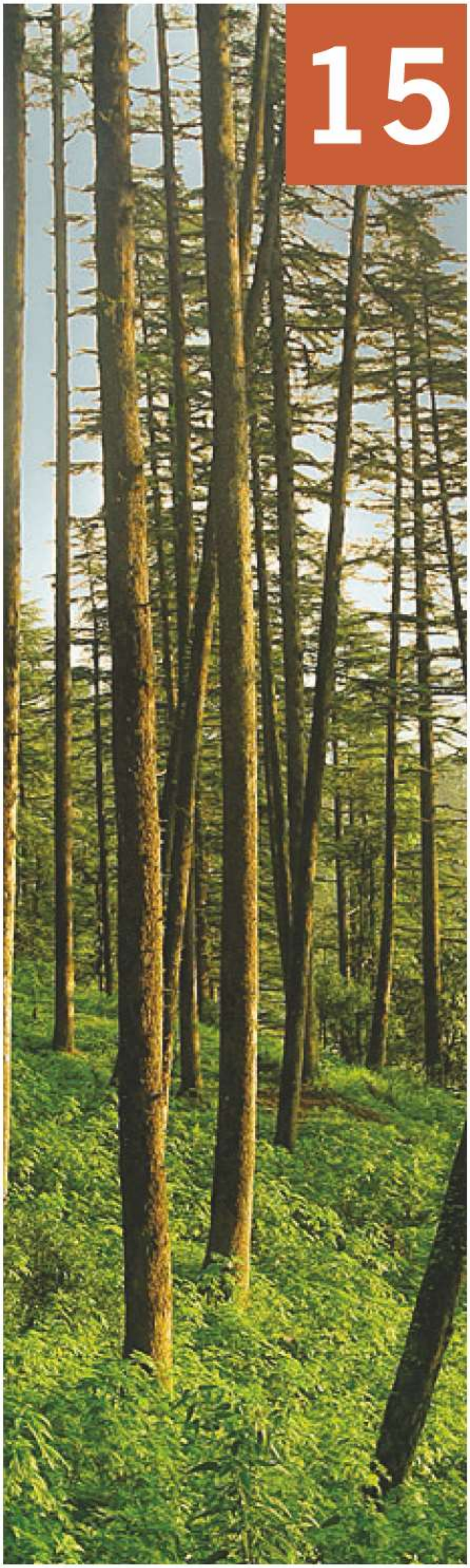
DATABASE AND CENTER OF EXCELLENCE FOR FGR

Accurate knowledge, and the availability of, and access to quality, reliable and up-to-date information are pre-requisites for the effective planning and efficient conservation of FGR that is relatively new for most countries and involves multiscale, multidiscipline, multisector, and multistakeholder approach. Advent in the IT and digital world and emergence of bioinformatics have opened up new vistas for the development of desired database so as to facilitate availability and easy access of valuable information to wider users. In addition, a Center of Excellence (CoE) for FGR has been envisaged that has a leading-edge knowledge, professional competency and expertise, shared facility, and able to provide leadership, best practices, research, and support for capacity development and field level conservation of natural heritage of precious FGR. This part covers single Chapter relevant to the development of database and the establishment of CoE-FGR.



DEVELOPMENT OF FGR DATABASE AND ESTABLISHMENT OF CENTER OF EXCELLENCE

15



Ginwal, H.S., Kumar, S. and Singh, R.

Information is a key for effective planning and efficient management of natural resources, sectors, and competent policy formulation and decision making. Conservation of complex and dynamic FGR is relatively new for most of the world countries as it involves multiscale, multidiscipline, multisector, and multistakeholder approach, and it is evolving. Accurate knowledge, and the availability of, and access to quality, reliable and up-to-date information as pre-requisites for conservation of FGR are reported to be poor in several countries. The advent in information technology, digital world, and RS and GIS technologies have opened up limitless opportunities for efficient decision making by the way of creation of databases. A database is a collection of connected data and a database management system (DBMS) is a piece of software that allows users to access data stored in a database. The logically structured data or database acts as a foundation for retrieving necessary information or making decisions by further identifying or processing the data.

Besides vital information and relevant databases, the complex nature of select sectors require 'a Center of Excellence (CoE)' as a knowledge management center having support of people, processes, and innovative technologies. The discipline of FGR involves a wide range of people comprising experts, professionals, practitioners, users, and beneficiaries. Thus, these varied people as 'think tank' matters. The conservation of FGR essentially requires multiple, interconnected and sequential processes relevant to documentation, germplasm storage, characterization, and conservation. These processes use varied field level methods and laboratory-based investigations involving different innovative technologies *viz*., digitization of herbarium, RS and GIS technologies, modeling, seed processing, tissue culture, cryopreservation, biochemical and pathological screening, DNA fingerprinting, nursery and propagation techniques, *in situ* and *ex situ* conservation.

Increasingly, varied sectors and specialized fields operating at the global, national and state levels are creating desired databases and CoEs for the respective sector, subject, discipline, theme, etc.

15.1

Creation of Database

A set of characteristics with same features or attributes represents an entity. These entities or 'Data' are the fundamental units of objects in a database and they are being referred as data item, data element, or data field. Data is information in a form or the building blocks of information that can be processed by a computer. A database is a computer-based record keeping system with an ordered collection of linked data kept with little redundancy in a way so that it can make cost effective service of providing information for different applications. The overall goal of a database is to manage information as a whole, and to make its access simple, quick, affordable, and adaptable for users. Database also allows retrieval, analysis and storage much easier. The database through centralized control guarantees data privacy and security. The consistency of data quality and content is also ensured. It responds to queries by user promptly and efficiently. Several users can access a database concurrently while maintaining data integrity. It also supports a complex file structure and access path, and allows any number of users to share data under its supervision. Database removes any superfluous data, prevent physical damage and illegal access to the data, and also allows its expansion. A database ensures standards for stored data formats, facilitating data transfer across systems. Thus, a database management system (DBMS) is complicated structure that manages, stores and manipulates data as well as the information. Database design is the design of database structure that will be used to store and manage specific type of data for a specialized utility. Generally, databases are found in four categories *viz.*, (a) bibliographic databases, (b) knowledge databases, (c) graphic oriented databases, and (d) decision making databases.

Importance of database in relation to complex and dynamic natural resource like a forest gets further enhanced due to multiplicity of factors *viz.*, vast array of species and associated genetic variability, varied ownerships and management regimes, hierarchical scales and different forest governance, etc. Further, in a human dominated country like India wherein a substantial population traditionally depend on forest resources for their subsistence and livelihoods creates a large forest-people interface which adds an additional dimension to a forestry database. Thus, richness and quality of large datasets incorporated in a database determines its effectiveness in the intended application. Broadly, forest management and conservation of FGR in particular involves two level applications within database so as to deal with the strategic planning at the national and state levels, as well as planning and prescribing field level management interventions and operations. A wide range of databases relevant to forestry in the country have been developed and managed at different hierarchical levels since the beginning of forest management on scientific lines. These databases deal with forest resources, forest protection, wildlife conservation, forest products and marketing, human and institutional resources, and varied fiscal aspects.

15.2

Establishment of Center of Excellence

The wider and multidisciplinary subject of forestry involves a variety of professionals and experts besides innovations and technologies. Often, such sectors or their relevant organizations become more complex when their teams are working in silos, not sharing their knowledge, and decision making in such specialized sectors invariably requires integrating knowledge and skills across interconnected multidiscipline. Further, this situation is compounded when an organization requires to engage multiple agencies, varied stakeholders and cooperate with other relevant organizations working for the allied fields or seeks to involve innovative technologies and tools. In such situations, the role of a leading 'Knowledge Management Center' or a 'Center of Excellence (CoE)'[i] is of utmost importance. A CoE is a premiere organization providing exceptional knowledge based on integration of multiple disciplines, extraordinary product, service, capacity, and innovative tools and technologies in an assigned sphere of expertise and within a specific field or sector consistent with the unique requirements and capabilities of the CoE organization.

Considering the complexity of conservation of FGR, the Pilot Project has envisaged the creation of a database and establishment of CoE-FGR.

15.3

Objectives

In view of the above backdrop, following objectives were set forth under the fifth Component on Database and CoE:

(i) Create a national level database so as to serve as an information repository, facilitating conservation and sustainable use of FGR.

(ii) Establish a Center of Excellence so as to serve as a center of knowledge, expertise, exceptional product or service relevant to complex and specialized discipline of conservation of FGR.

15.4

Creation of FGR Database

Genetic diversity is the subset of biological diversity, and is the mainstay of biological stability. Genetic variation within a species enables it to adapt to changing environments, including the effects of climate change and emerging pest outbreaks and pathogenic infestations. It also provides the foundation for present and future selection and breeding programs. Besides its irreplaceable contribution to environmental sustainability, FGR provide a direct food source for humans and animals, even at times when annual crops fail. Inventory, field level assessments, characterization and monitoring are prerequisites for generation of information and knowledge essentially required for proper understanding of trends in the status of FGR for appropriate decision making in the sustainable management and use of FGR. Since, most forest species grow wild, long lived and are not being domesticated, the in situ conservation is the most widespread prevalent conservation practice. The effective management of FGR can be achieved only when their conservation efforts are focused at all levels (ecosystem, species, and gene), while involving varied sectors, agencies, users and beneficiaries.

Presently, comprehensive knowledge on FGR is grossly inadequate for a well-planned policy and management interventions. Inventories of habitats in the context of FGR species and relevant quantitative information on their uses, threats, distribution, and regeneration status is mostly lacking. The existing quantitative or qualitative information on FGR wherever available is ad hoc in nature, piecemeal, and fragmented in time and space. Currently, there is no mechanism in the country to ascertain the status of FGR diversity of a given region/ State at a given point of time so as to determine the trends and take appropriate management actions. Most information is widely scattered and available in working plan of an individual FD. The sustainable use and management of FGR requires information by decision-makers, scientists, and other users. Because FGR related information is not immediately at hand, it is often not applied in policy or management decisions that affect the organisms involved, nor is that information readily accessible by the users.

Comprehensive data on the distribution, regeneration status, seed viability and storage, seed germination protocols, and genetic diversity pattern of ecologically and socioeconomically important forest tree, shrubs and woody climber species, that are endangered or threatened in India is not available or is very limited. Presently, information on FGR in the context of country/ any State is not available on a single platform. There is an urgent need to develop a platform which will provide basic and comprehensive information on FGR for their long-term conservation. FGR Database will provide the basic information about the distribution, regeneration, and all other parameters which will be helpful in policy making and development of conservation strategy. Considering the vastness of FGR and significance of baseline information on their status, trends, and characterization, creation and maintenance of FGR database at different hierarchical governance levels was recognized by the Pilot Project.

15.4.1

Functions of FGR Database

The FGR database is expected to perform the following functions:

- Serve as a national repository for the storage, display and dissemination of FGR data through the online web portal.
- Accumulate, digitize, utilize, share and update FGR data and information across the world.
- Summarize the status of major FGRs with respect to their taxonomy, distribution, characterization, and regeneration, and offer insights on their germplasm storage, propagation, conservation, and use and sharing of information.
- Facilitate and promote the use of FGR data to public, stakeholders and decision makers for networking, creating awareness and conservation of FGR.

15.4.2

Strategy

The Government of India, MoEFCC has initiated a National Program on Conservation and Management of FGR in 2016 in accordance with the Global Plan of Action for the Conservation, Sustainable Use and Development of FGR, and initially launched the Pilot Project specific to the Himalayan State of Uttarakhand as the demonstration site. Following this, the countrywide program on FGR conservation supported by CAMPA Funds commenced in 2019. In view of this, the Pilot Project started working on the FGR database in the context of Uttarakhand, hereafter named as 'UK-FGR' with a visualization to form it a part of the larger FGR database for the whole country referred as the 'IND-FGR'. Concurrently, during the Phase I of the project, similar efforts will be made for other States/ UTs of the country so as to achieve the national goal of the IND-FGR.

Like most world countries, specific information on FGR in the country is generally poor or widely scattered. The proposed database aimed to improve the availability of, and access to, information on FGR by promoting surveys, field level assessments, inventories, and development of protocols for germplasm storage, propagation, characterization, and conservation of FGR. The strategy aimed to mainstream information technology in improving vital reference data on forest resources. The design and development of UK-FGR considered hierarchical information needs, comprehensive nature in structure and content, build upon the information flow process from multidiscipline sources and stakeholders, and visualized simple and user-friendly approach.

15.4.3

The Approach

The approach adopted for the design and development of UK-FGR included the following key steps:

15.4.3.1

Need Assessment

The need assessment was the foremost step in the design and development of database. This was achieved through: (a) review of concepts, strategies, approaches, scientific reports, and existing databases relevant to conservation of FGR at the national and global level; (b) consultative process involving multidiscipline experts, scientists, forest practitioners, and users; and (c) appraisal of project documents. Task Leads/ Coordinators/ Investigators made presentations highlighting the requirements, activities, and the type of data generated. This allowed a preliminary insight on the components, sub-components, tasks/ activities, outputs and outcomes besides the existing information flow process and partners involved in the program. The need assessment also provided an understanding on the likely contributors, and clientele which will ultimately use the database. During the process of need assessment, formats for input information and varied outputs were also collected.

15.4.3.2

Conceptual Design

The process of need assessment facilitated the development of conceptual design. In all, four Components relevant to FGR Conservation were recognized (Fig. 15.1). These were considered as four modules, hereafter named as: (i) F-DOC (FGR Documentation); (ii) F-SGS (FGR Seed and Germplasm Storage); (iii) F-CHR (FGR Characterization); and (iv) F-COS (FGR Conservation). Thus, the conceptual design envisaged that the state specific UK-FGR will be first developed, keeping in view that it will ultimately become a part of larger national level database (IND-FGR). Initially, the UK-FGR would be constructed around four above stated modules relevant to four components of the Pilot Project and also in accordance with the national priorities incorporated in the Global Action Plan on Conservation of FGR. Each module would have three to four sub-components, while each sub-component would have multiple specific activities. The consultative process emphasized that initially database should be the sole effort of different specialized disciplines/ departments of forestry within the setup of FRI. However, ultimately the database should be in a position to take optimal advantage on the valuable information viz., species occurrence in FDs/ PAs, population structure, regeneration status, etc. available in forest working plans, and wildlife/ PA management plans prepared/ revised by the State Forest Department. Likewise, the SFD can provide key information on *in situ* and *ex situ* conservation. Presently, information on *circa situm* repository (remanent forests/ planted trees) in agricultural landscapes is grossly inadequate. This needs to be generated by joint efforts of FRI and SFD so that it can contribute vital information to the database.

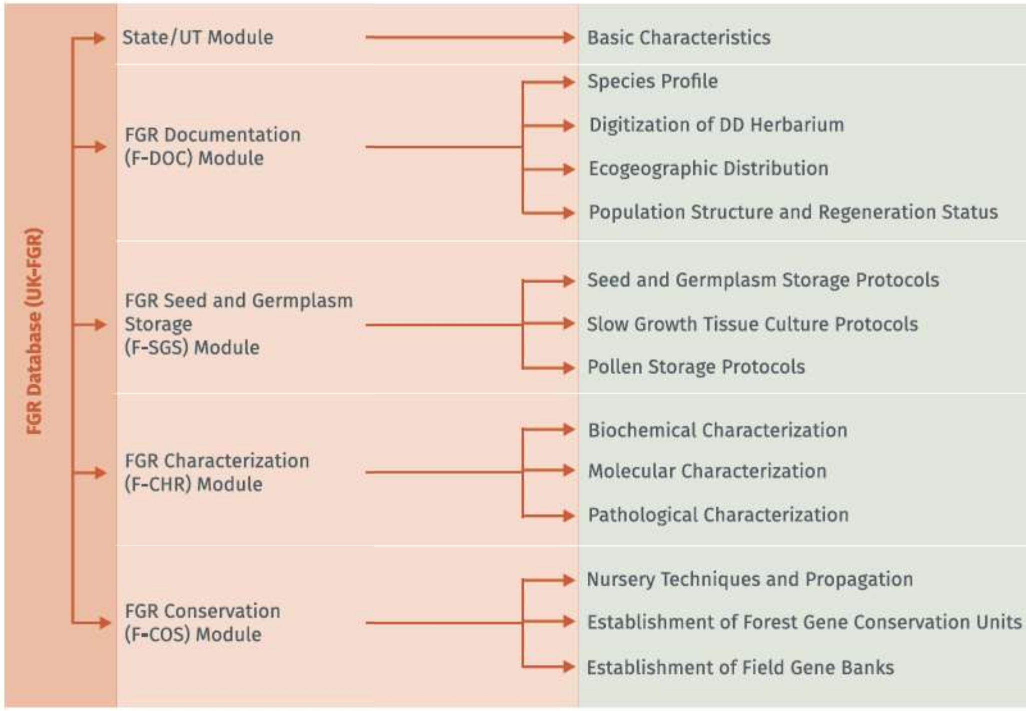


Fig. 15.1 Structure of UK-FGR Database incorporating Four Modules and Various Sub-Components

15.4.3.3

Detailed Design

The output of conceptual design was shared with experts and the project proponent. The review and feedback obtained helped the professional agency M/s Reckon Web Solutions, Dehra Dun, engaged by FRI in the development of detailed design of database incorporating the overall architecture - modules, sub-modules, processes (logical input/ output-process number, logical data, input/ output forms, source/ destination, features and functionalities, entity- attribute list, relationship with other entities within the module) besides preliminary data volume estimates based on need analysis and assumptions, the type of queries/ reporting, and report generation. Details on roles of administrator, data operators, information contributors, etc. were defined. Information on system software and storage, information flow and application architecture, infrastructure architecture, multiuser configuration, networking architecture, integration architecture, back-up/ recovery strategy, and security were spelt. The database offers georeferenced information on the ecogeographic distribution of FGR species and *in situ* and *ex situ* conservation efforts towards conservation of FGR.

The primary goal of FGR database was to develop a robust database that may be used for the storage and retrieval of a wide variety of data types for forest plant species. The FGR database's design offers a generic database that can be used as a gateway to the data by interfaces that can range in complexity from simple to complex.

MYSQL platform and codeigniter3 framework was selected for the development of UK-FGR database because it is relatively fast, open source, reliable, scalable and highly secure platform that can store records in multiple, separate, and highly codified tables rather than a single repository. In order to create the UK-FGR database, PHP 7.2 programming language and Codeigniter3 framework were utilized. This version of PHP offers improved developer features as well as security and performance improvements and Codeigniter3 framework offers pre-built libraries for connecting database and carrying out various activities like sending emails, uploading files, managing sessions, etc. The detailed design appropriately provisioned for inbuilt flexibility to expand, modify and add modules/ sub-modules/ activities/ input data, query, etc. in future, if so required.

15.4.3.4

UK-FGR Implementation Plan and Periodic Review

An implementation plan was prepared so as to ensure timely complete development of database as envisaged in the detailed design. Once, the database was developed, varied data was populated for sample run, testing and validation. Observed glitches and bugs were attended. Some of the screenshots of UK-FGR database are presented so as to highlight home page, modules, sub-modules, and output format (Fig. 15.2 to 15.4). This enabled a functional database based on the Pilot Project implemented in the Himalayan State of Uttarakhand. Mechanism for periodic review of functionalities and performance of database were part of the implementation plan.

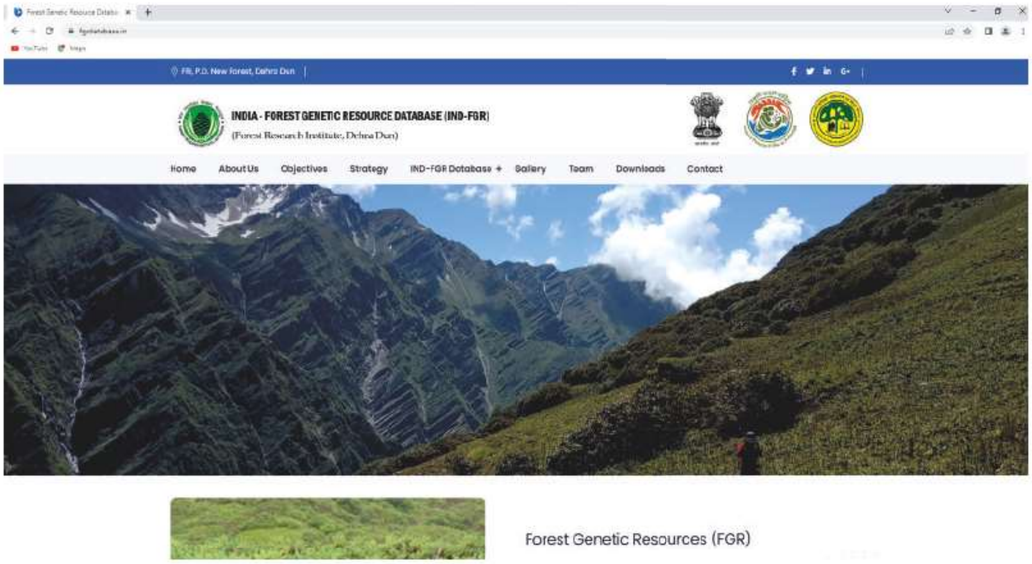


Fig. 15.2
UK-FGR Database Home Page

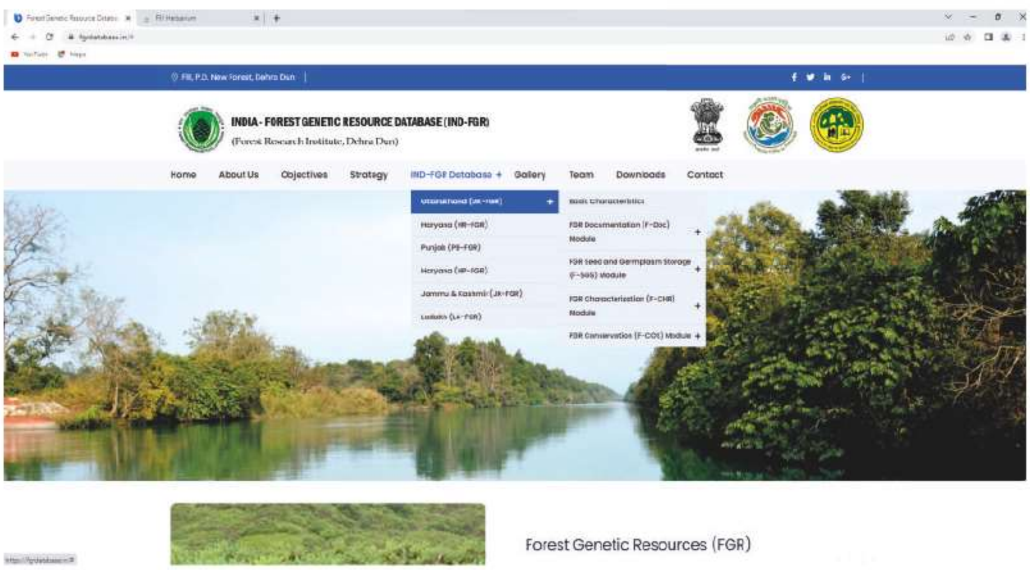


Fig. 15.3
UK-FGR Database Architecture Highlighting Modules and Sub-Modules

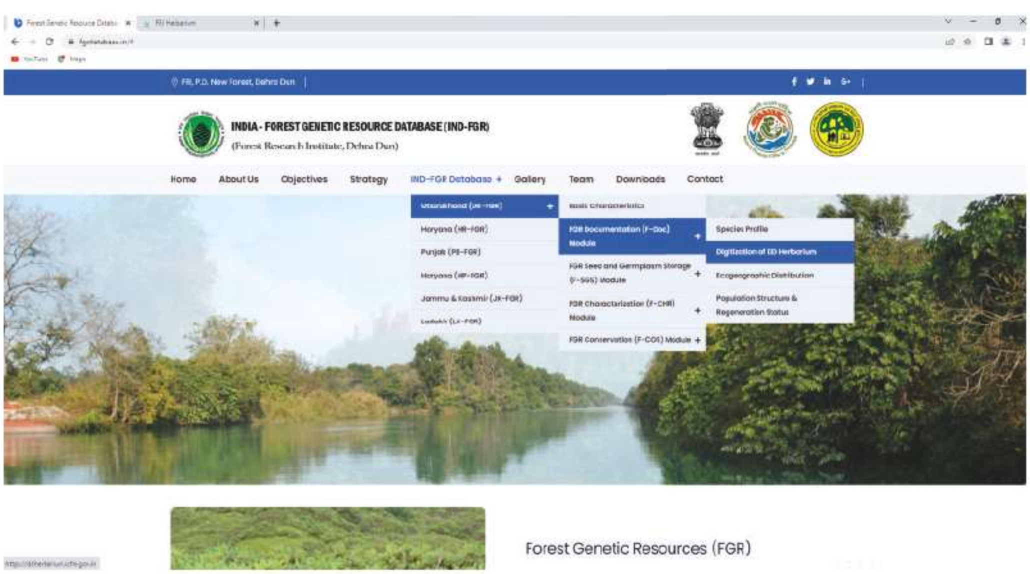


Fig. 15.4
UK-FGR Database: Report Generation

15.5

Establishment and Operationalization of CoE-FGR

During the last decade, there was a growing appreciation at the global level about the role of FGR in addressing challenges of biodiversity loss, food and water security, poverty alleviation, environmental stability, and need to develop better understanding and conservation of FGR. At the same time, most world countries including India have realized the paucity of comprehensive information at all levels on one hand, and sorry state of affairs in respect of FGR mainly due to the absence of any national level designated agency and program to provide focused attention on the conservation, sustainable utilization and development of these vital, unique and irreplaceable resources for the future. In response to this priority felt needs at the global and national level, the National CAMPA Advisory Council (NCAC) of MoEFCC, GoI had sanctioned a Pilot Project to FRI for 'Creation of Center of Excellence on Forest Genetic Resources (CoE-FGR)' in the year 2015. Accordingly, the CoE-FGR was created at FRI by the Institute's Order No. 9-108/DGTP-CoFGR/2016 dated 4 February, 2016. As per the order, Project Director and Project Coordinator were designated, and four Working Groups/ Cells (FGR-Documentation, Seed and Germplasm Storage, Characterization, and Conservation) were constituted, initially each having a core team of four Scientists as Investigators. Five Divisions *viz.*, Systematic Botany, Silviculture, Genetics, Chemistry and Pathology of the Institute were involved in the working groups. A senior scientist among the team for each group was designated as the Key Person. The Order also stipulated that the CoE-FGR will create an interactive computerized database on FGR in the context of India. It was decided to set up the administrative unit of the CoE-FGR in the Division of Genetics and Tree Propagation of FRI.

15.5.1

Vision

Serve as a specialized national nodal agency to steer, coordinate and monitor the documentation, augmentation, conservation and management programs for FGR in the country. The Centre will be undertaking works related to exploration, documentation, evaluation, conservation, management and development of FGR. The Centre will fill the long-standing gap in effective FGR conservation.

15.5.2

Functions

The CoE-FGR serves as 'One Stop Centre' for information and action on the FGR of the country and performs the following major functions:

- Prepare comprehensive inventory of country's FGR with ecogeographic distribution maps of priority FGR.
- Develop priority list of FGR, based on the assessment of their conservation status, with road map and action plan for their conservation and development. Assess the living stock, harvesting regime / exploitation of the prioritized species.
- Collect seeds of important FGR species with passport data and deposit them in Seed Banks for medium and long-term conservation/ cryopreservation, and use in FGR improvement programs.
- Evaluate and characterize important FGR for traits like morphology, growth, biochemical profile, genetic diversity, and resistance to disease and pests, etc.
- Develop in situ forest gene conservation units based on genetic diversity and population structure of important FGR.
- Establish *ex situ* field gene banks for conservation of germplasm of species with fragmented, small sized and marginal populations.
- Develop agro-techniques of Red-Listed FGR species for multiplication of their germplasm and initiate need-based restoration, species recovery and conservation programs in respect of such species.
- Establish and service information and research network of organisations engaged in research on FGR.
- Develop and maintain a national level 'Seed Research and Referral Centre' for seeds of forestry species at FRI, Dehra Dun.
- Develop and operationalize a comprehensive computerized database on FGR of India.
- Beside above, the Centre will also act as an accredited national node on issues pertaining to global conventions/ initiatives on FGR. The Centre also provides advisory services whenever called upon to do so.

15.5.3

Advisory Board of CoE-FGR

The CoE-FGR, currently specific to Uttarakhand is functional since 2016 at FRI. It has taken almost five years to develop and evolve as comprehensive information on prioritized FGR has started flowing after three to five-year of research efforts. The experience illustrates that a specialized national nodal agency on FGR cannot work effectively and efficiently in the absence of an Advisory Board at higher level, represented by the professionals, experts, and field practitioners working in the field of conservation of FGR. Notification of CoE-FGR by the MoEFCC, GoI is awaited in response to the proposal and request submitted by the DG, ICFRE. The proposed constitution of the Advisory Board as per the proposal is presented in Table 15.1.

Table 15.1 Proposed Constitution of the Advisory Board of CoE-FGR

i	Director FRI, Dehra Dun	Chairperson
ii	Permanent Members	
	Dy Director General (Research), ICFRE	Member
	Director, NBPGR, New Delhi	Member
	Director/ Officer In charge, BSI, Dehra Dun	Member
iii	Nominated Members	
	Two PCCF and HoFF, States	Members
	Two Directors, ICFRE Institutes	Members
	Two Experts and Specialists in the field of Plant Genetic Resources/ Tree Genetic Resources	Members
	Two Subject Experts from Central/ State Universities	Members
iv	National Project Coordinator FGR	Head of Centre and Member Secretary

The term of members nominated by the Chairperson will be for two years. This Advisory Board will meet at least twice a year to advise and review the progress of works of CoE-FGR. The terms of reference for the Advisory Board are as given below:

(i) To prioritize and approve the Annual Plan of Operation to carry out the planned activities to achieve laid objectives of the CoE-FGR.

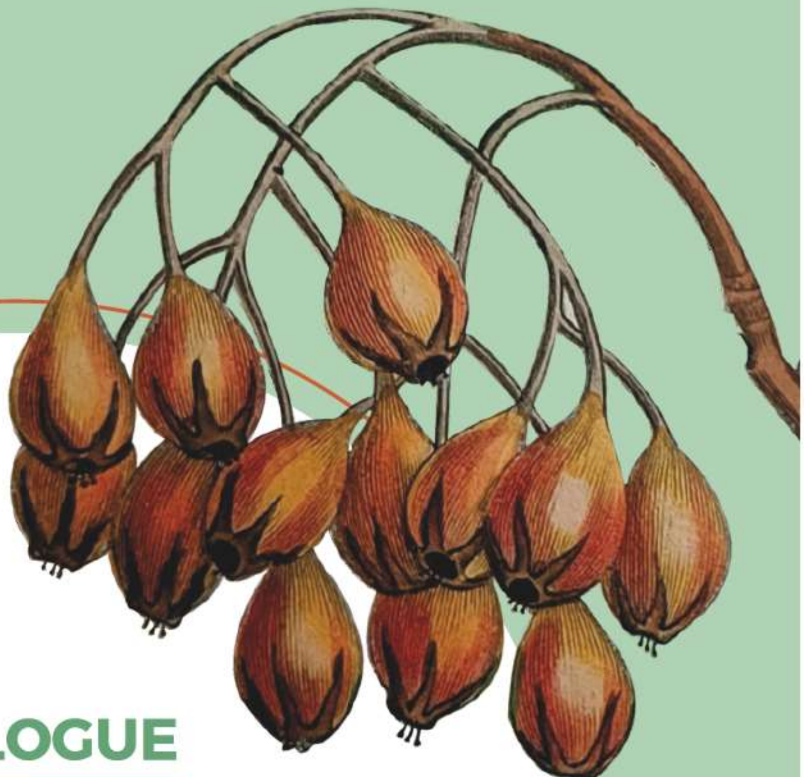
(ii) The Board will review the activities and provide feedback on the R&D initiatives giving suggestions for improving and sharing of knowledge.

(iii) The Board will also periodically review the progress of research projects run by CoE-FGR.

The professionals from involved institutions and partner organisations will support the Centre's leadership team in strategic planning, expanding to new initiatives, and identifying the priority/ problem areas in the relevant field for undertaking focused research to arrive at practical solutions in the matter. The CoE-FGR will serve as a common facility for scientist/ researcher in India by extending facilities and conditions for screening, conservation of germplasm and breeding populations. In addition, the CoE-FGR will establish linkages with international organizations including Universities for collaboration in specific fields and sign the Memorandum of Agreement. Presently, the CoE-FGR has the Perspective plan and secure funding for executing its activities until 2025. The information generated by the centre will be shared with stakeholders (SFD, institutions, individuals, other agencies) on request. The permanent and contractual scientific staff of FRI will provide their services and contribute for the growth of database. However, the CoE-FGR will be able to hire outside domain experts/ consultants as per the need, following standard procedures and guidelines issued by GoI from time to time in this regard.

PART

07

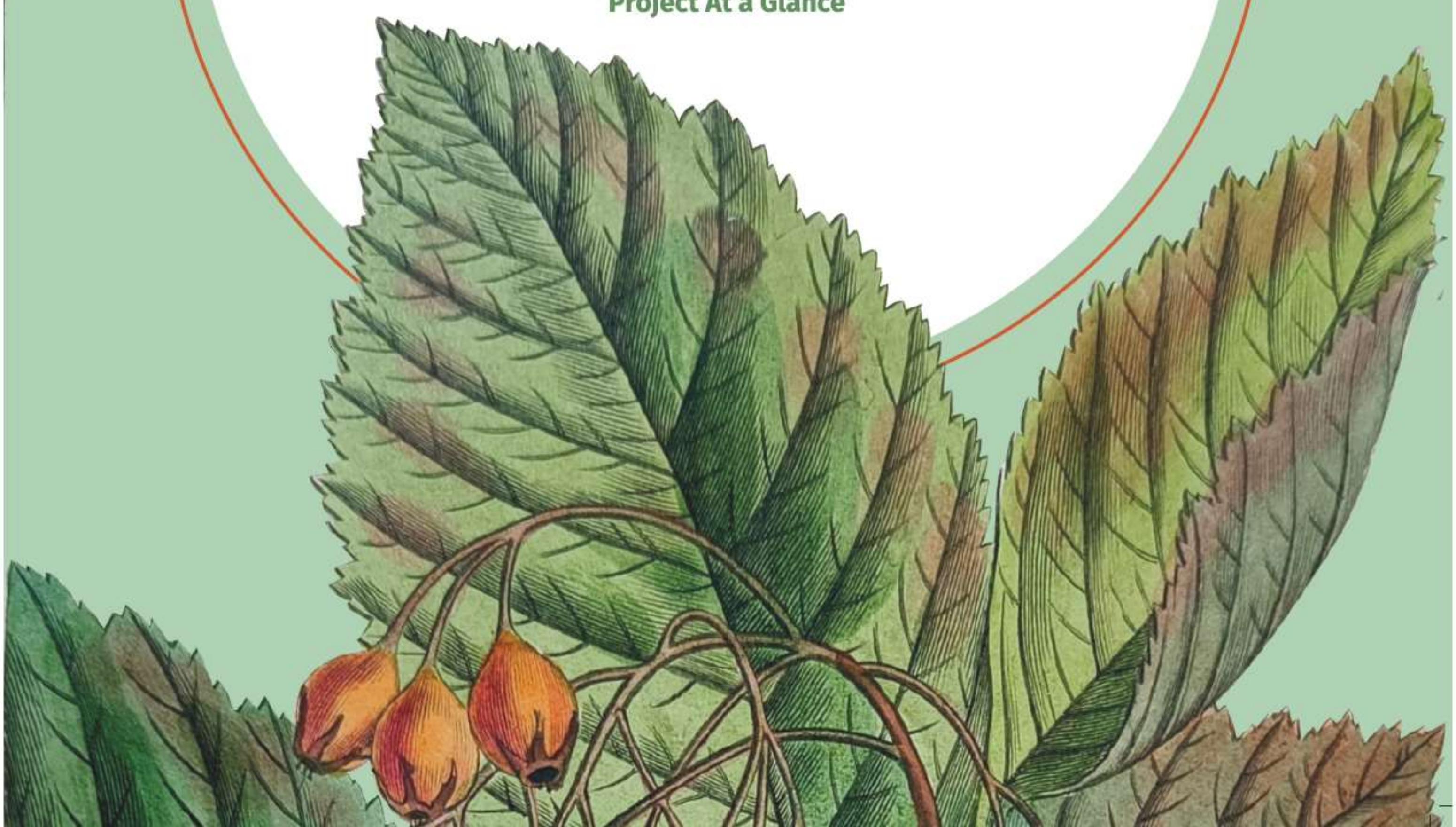


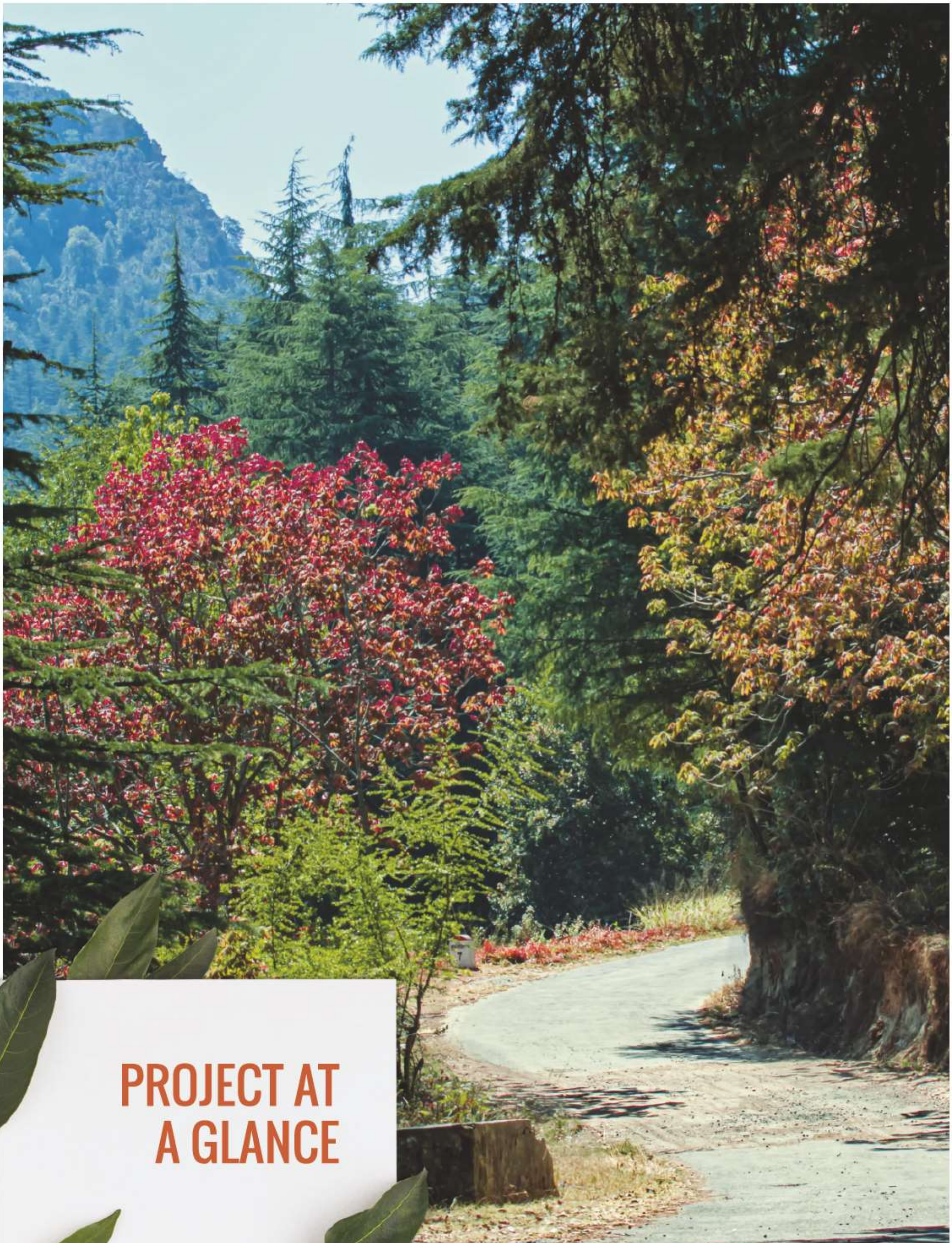
EPILOGUE

The major Project like the present one on the conservation of FGR that involved multiple discipline, multiscale, and multitechnique requires careful synthesis based on an integration of varied research findings emerged from different Components. This part specifically attempts to provide an overall synthesis and covers single Chapter.

Chapter 16

Project At a Glance





PROJECT AT A GLANCE

16

Ginwal, H.S., Rawat, A., Singh, S. and Mathur, P.K.

Forests are at the heart of the global sustainable development goals as they have enormous potential to support sustainable development pathways and central to realize this. Most of the terrestrial biodiversity occurs in the world's forests and collectively diverse forests across the globe contain more than 60,000 tree species besides a wide array of plant diversity belonging to different habits and taxonomic groups, and associated diversity of faunal species and microorganisms. This diversity has evolved over 3.5 billion years, and is a result of speciation, migration, extinction, evolution, and more recently human activities. Biological diversity or biodiversity embraces the diversity of all life on the Earth. Broadly, it has been distinguished at three hierarchical levels (Ecosystem, Species, and Gene) and values of biodiversity are generally attributed to these levels. Typically, the ecosystem level diversity offers environmental and life support values, while material goods are provided at the species level. The improvement of production depends on the availability of genetic variation. Forests perform varied functions *viz.*, providing habitats, enriching soil fertility, controlling soil erosion, nutrient cycling, maintaining catchments of rivers and hydrological regimes, purifying water, capturing, and storing carbon, mitigating climate change, etc. besides consumptive (food, fodder, fiber, fuelwood, timber, medicine, etc.) and non-consumptive (recreation and tourism) uses of forest resources. Although, forests have strong linkages with human well-being and healthy planet, much of the human society since time immemorial has at-least some interaction with forests and has displaced and exploited them. Hence, human impacts on forests date back to antiquity and even to prehistory. Globally, forests have shrunk in their extent, and suffered in terms of quality, productivity, and diversity, especially genetic diversity, and forest genetic resources (FGR).

16.1

Genetic Diversity and Genetic Erosion

All living organisms (plant, animal, microorganisms, or other origin) contain genetic or heritable material, essential for existence, reproduction, adaptation, and evolutionary processes. The total genetic material of an organism has been termed as a genome consisting of long DNA molecules referred as chromosomes. Plant contains three types of genomes *viz.*, nuclear, chloroplast and mitochondrial. A chromosome may contain part or all the genetic material of an organism, carrying genetic information in the form of genes. Genes are DNA sequences assigned with specific functions while variant in DNA sequence at a given gene is referred as allele which provide a common way to measure genetic diversity. The 'genetic diversity' denotes the total amount of genetic differences within a species, referred as intra-specific variation. Since, a species may have multiple populations, intra-specific variation could be either inter or intra population variations (among and within population genetic diversity). The differences in DNA sequences of a genome make an individual unique and such differences have been termed as the genetic variations. The condition of having two different alleles at a locus is referred as heterozygosity and it is fundamental to the study of genetic variation in populations and a common way to measure genetic diversity. Genetic diversity is an essential foundation for evolutionary change and is critical for species to adapt to changing climate, habitats, and biotic interactions including novel diseases.

Genetic erosion occurs due to one or more of: (a) loss of alleles i.e., gene variants; (b) decrease in heterozygosity or genetic drift; (c) loss of distinct populations of significant conservation units or fragmentation, small population size and high inbreeding; (d) disruption of processes maintaining genetic connectivity or altered gene flow; and (e) high levels of hybridization. In short, 'prevention of genetic erosion' is approximately synonymous with 'genetic diversity is maintained.' Safeguarding genetic diversity would, thus require maintenance of a sufficient representative amount of genetic diversity of a species' geographic range including genetically distinct populations and the full range of environmental heterogeneity. In other words, actions for performed *in situ* or *ex situ* conservation aim to characterize, slow, arrest or reverse genetic erosion, and promote the processes ensuring adaptive potential.

16.2

Forest Genetic Resources

Forest Genetic Resources (FGR) form an important subset of biodiversity, defined as 'the heritable material contained within and among tree and other woody plant species that are of actual and potential economic, environmental, societal, and scientific value.' The wording of this definition emphasizes on two qualifying elements *viz.*, functionality and value. 'Genetic resources' means genetic material of actual and potential value while 'genetic material' relates to functionality aspect by way of 'units of heredity' which is a dynamic element of biology. FGR are unique and irreplaceable resources, vital for resilience, productivity, diversity, adaptation and evolutionary processes of forests and trees, and essential for humanity and forest-based other life forms. In short, FGR and genetic diversity within them are essential for ecosystem stability, persistence of species and maintaining fitness, resistance to biotic and abiotic stresses, potential for adaptation to climate change, artificial selection and tree improvement, insurance for future, and foundation for evolution. In India alone, more than 340 million people are estimated to be dependent on FGR for their livelihoods.

16.3

Factors Influencing FGR

Across globe, most forests are home to a range of native, non-native, and naturalized tree and shrub species that have adapted in various ways to their growing environments owing to natural processes and human induced activities. Much of the genetic diversity in FGR has evolved over generations as species have adapted at a fine scale to local conditions while influenced by natural processes *viz.*, natural colonization and selection, gene flow, and mutation, and enhanced anthropogenic activities *viz.*, change in land use, forest management practices, agriculture expansion and intensification, forest fire, unsustainable harvest, introduction of invasive exotics, developmental activities, etc. Most of these factors, particularly forest management practices modify forest composition, tree density, age class structure at different stages during a forest stand rotation besides strong effects on genetic diversity, connectivity, and effective population size. Further, human aggravated climate change is having wider implications in form of population bottle neck, fragmentation and isolation, reduced regeneration, and population size, altered distribution range of FGR species and phenology, asynchrony of pollinating and seed dispersing agent, modified seed biology and germination behaviour, and introduction of pathogens and pest infestations. Since trees and FGR species are long lived and occur in dynamic complex environment, detecting which environmental factors affect most of their genetic diversity is not straight forward.

16.4

Global Developments and Initiatives for Conservation of FGR

Despite ongoing varied initiatives and concerted efforts at all levels, biodiversity is losing and deteriorating worldwide, and this decline is projected to continue or worsen under business-as-usual-scenarios. The global instruments (policies, conventions, treaties, bilateral and multi-lateral agreements, etc.) of direct relevance to FGR fall under the purview of environmental, agricultural, or forestry sectors, and associated frameworks have come into existence and greatly increased at both international and national levels in response to enhanced environmental awareness, national agenda, and international obligations and programs. In past seven decades or so, international priorities in genetic resources have gradually moved from initial focus on plants, agricultural crops to domesticated animals, fisheries, human genomics, microorganisms and finally to forest trees and woody plants as these different sectors form a part of wider biodiversity, have strong cross-sectoral interconnections and evident sharing of common technological tools.

The global synthesis on The State of World's Forest Genetic Resources (SOW-FGR) by FAO in 2014 based on information provided by 86 countries highlighted that effective management of FGR requires the availability of accurate knowledge and information on ecosystem and species. Presently, the most widely used estimates for number of tree species range from 80,000 to 1,00,000, but the range of published estimates is much wider indicating the need for further efforts in botanical assessments. Current botanical knowledge greatly varies across countries and often confuses in nomenclature owing to multiple synonyms, shrinking pool of taxonomists and professional forest botanists, and the advent of molecular systematics. Nearly half of the forest species reported by the countries are threatened. Eight thousand forest species are used and nearly one-third of them are actively managed. Economic value is the decisive factor in setting management priorities. Most species are conserved *in situ* in naturally regenerated and planted forests. Effective *ex situ* conservation programs are restricted to limited species and populations. Tree improvement greatly enhances productivity and offers potential for adaptation to changing climate. Policies and institutional frameworks are insufficient. Moreover, in most instances, the sorry state of affairs in respect of FGR is primarily due to the absence of any national level designated agency and program to provide focused attention and priority for the conservation and development of this important and critically placed resource. Nevertheless, emerging technologies open new avenues in management and conservation of FGR. Certainly, knowledge of FGR is inadequate for well informed policy and decision making or management in most countries even though the number of studies and the number of species assessed have enhanced significantly. So far, these studies have described genetic parameters for less than one per cent of tree species.

The findings and recommendations incorporated in the SOW-FGR formed the basis for the development of *The Global Plan of Action for the Conservation, Sustainable Use, and Development of Forest Genetic Resources* which was released by FAO in 2014. This comprehensive global plan of work on FGR identified four priority areas, and altogether 27 strategic priorities. Four priority areas included were: (i) improving the availability of, and access to information on FGR; (ii) conservation of FGR (*in situ* and *ex situ*); (iii) sustainable use, development, and management of FGR; and (iv) policy, institutions, and capacity building. Implementation of the Global Plan of Action was expected to strengthen the management and sustainability of FGR while assisting countries in integrating FGR conservation and management needs into wider policies, programs and frameworks of action at different hierarchical governance systems besides developing sound technical and scientific programs for the successful management of FGR and significantly contributing towards the global goals of biodiversity conservation, climate change and sustainable development.

In the long process of development of SOW-FGR and the Global Plan of Action by FAO Commission on Genetic Resources (FAO-CGR), many regional, sub-regional and ecoregional programs, networks, and initiatives on FGR came into existence and they meaningfully contributed towards creation of awareness, knowledge generation and sharing, capacity development, and even formulation of region/ country specific strategies and programs.

16.5

Indian Initiatives for Conservation of FGR

India's ethos and culture promotes conservation of nature, particularly forests as a substantial population of the country solely depends for subsistence and livelihoods on diverse forests. Despite small geographic extent, populous and one of the developing countries in the tropics, India's contribution to world's biodiversity is about eight per cent and has been designated as one of the seventeen megadiverse countries and ranks eighth in the world. Forests in India or the Indian Forestry has a long history of management. The colonial regime played a pivotal role in the management of Indian forests by way of reservation of forests; establishment of forestry infrastructure including SFDs, and research and training facilities; and formulation of forest policies, laws, strategies, and working plans for practicing silviculture-based forestry. In the past seven and a half decades after the independence of the country, the paradigm shift from 'production forestry' to 'conservation forestry', supported by relevant instruments, and launch of wide range of countrywide conservation initiatives and programs have not only helped in effective management of forests, conservation of biodiversity, environmental management, and restoration of degraded habitats and ecosystems but also in ensuring sustainable livelihoods, continuance of ecosystem services, and socioeconomic development. These efforts have also directly or indirectly helped immensely in conservation of FGR. However, the burgeoning human population, and developmental pressure exert enormous challenges and threats to forests and other natural ecosystems, and associated biodiversity. There is a growing realization that under the business-as-usual-scenarios, it would be difficult to maintain the existing natural wealth of country's living resources, specially FGR. Thus, like most world countries, India also aims to galvanize an urgent and transformative action to arrest, halt and reverse the loss of biological diversity, particularly genetic diversity and FGR.

Although India has one of the internationally acclaimed oldest forestry research organizations i.e., FRI; well laid infrastructure of forest reserves and their management; network of PAs and other conservation areas; ICFRE with a network of countrywide institutions; BSI for botanical exploration and floristics; and other reputed national/ state level government and non-governmental organizations contributing on wider fields of forest vegetation, forest resources and management, and biodiversity conservation, a well-articulated and comprehensive national level strategy and agenda for the conservation of FGR in the country neither was formulated nor programs and projects in this direction to elicit the desired support at the national level until 2015. Thus, efforts for conservation of FGR remained ad.hoc and piecemeal for a long period and obviously gaps in the knowledge, and problems in conservation of FGR are evident besides pertinent research questions.

16.6

National Program for Conservation and Development of FGR

In accordance with the Global Plan of Action for FGR, and on the advice of the MoEFCC and ICFRE, FRI prepared a 20-year perspective plan titled 'National Program for Conservation and Development of Forest Genetic Resources (2016-2035)' incorporating an implementation strategy for execution of Pilot Project - 'Center of Excellence on Forest Genetic Resources (CoE-FGR) of India (2016-21)' and details on the subsequent three phases with an overall outlay of Rs. 622.10 million. After considerable deliberations on the proposed comprehensive perspective plan, the MoEFCC decided to initially establish CoE-FGR at FRI and implement the 5-year Pilot Project on FGR in the State of Uttarakhand with a budgetary allocation of Rs 86.12 million under the Ad.hoc CAMPA Fund. The activities of the CoE-FGR at FRI and the Pilot Project commenced in April, 2016 after the engagement of project staff. The Pilot Project was granted extension in view of interruption of activities on account of the Covid-19 pandemic and lock down and successfully completed in June, 2022.

16.7

Establishment of CoE-FGR

The CoE-FGR was established and made functional in 2016 utilizing the available expertise across Forest Botany, Silviculture, Chemistry, Pathology, and Genetics Divisions of FRI and varied facilities (DD Herbarium, Botanical Garden, Arboretum, National Forest Library and Information Center-NFLIC, IT and GIS, and analytical/ research laboratories) besides involving experts, professionals, and practicing foresters from time to time as per the need.

16.8

Pilot Project

The Pilot Project primarily included four thrust areas *viz.*, (a) FGR Documentation, (b) FGR Seed and Germplasm Storage, (c) FGR Characterization, and (d) FGR Conservation, referred as 'Components'. Each of these four components included three to four sub-components and allied tasks. In addition, the project envisaged an important task on the creation of FGR database.

16.8.1

Demonstration State

The MoEFCC selected the Himalayan State of Uttarakhand for the purpose of implementation and demonstration of the Pilot Project in view of the fact that the State is uniquely placed and represents nearly one-fourth diversity of forest sub-types described for the entire country besides it is geographically, ecologically, socioeconomically and culturally diverse owing to varied landforms, extremities in the altitudinal gradient and climatic conditions, affinity of local communities with forests, and long history of forest management. Uttarakhand is exceptionally rich as 71.05 per cent area of the State is Recorded Forest Area (RFA) and represented by diverse forests along the altitudinal gradient covering total forest cover to the extent of 24,305.13 km^2 or 45.44 per cent of the State's geographical area. These forests are known repository of forest biodiversity including FGR. In addition, the prestigious FRI is in the capital town of Uttarakhand with optimal advantage of headquarters of the Uttarakhand Forest Department (UKFD) and the presence of several reputed National/ State level forestry and allied organizations including the Northern Station of BSI, FSI, WII, IIRS, etc.

16.8.2

The Approach

The conservation of FGR seeks a comprehensive multidiscipline, multiscale, multisector, and multistakeholder approach as the Pilot Project incorporated four Components besides creation of database and the establishment of CoE-FGR. Thus, the project adopted a holistic, hierarchical, participatory, and multipronged approach including: (a) review of existing information; (b) wider and extensive consultative process; (c) field exploration, surveys, assessments, and documentation; (d) modernization and digitization of DD Herbarium; (e) collection of seeds, processing, viability, and vigour rials, and storage of priority FGR species; (f) medium to long term storage of pollen and tissues; (g) characterization based on biochemical, genetic and pathological attributes; and (h) *in situ*, *ex situ* and *circa situm* conservation measures. The consultative process immensely helped in prioritization of 250 FGR species from the perspective of documentation of their distribution, population structure, regeneration status, threat perception and uses. In addition, 50 FGR species were prioritized for potential ecogeographic mapping based on predictive modeling using bioclimatic attributes. Ten tree species each for pollen storage and tissue culture were selected. Further, five tree species were evaluated for biochemical, genetic, and pathological characteristics. The task on nursery and propagation techniques was integral to *in situ* and *ex situ* conservation measures by way of establishment of Forest Gene Conservation Units (FGCUs), and Field Gene Banks (FGBs), respectively. Concurrently, the process of developing FGR database was initiated. As a part of the consultative process, the inception and experience sharing and dissemination workshops were organized involving stakeholders, mainly focusing on forest policy and decision makers, field practitioners, and subject matter specialists.

16.9

Outputs, Achievements, and Key Recommendations

Component-wise outputs, achievements and key recommendations are summarized and highlighted below one by one:

16.9.1

FGR Documentation

The foremost priority of the Pilot Project was to improve the availability of, and access to, information on FGR by way of prioritization, documentation, digitization of herbarium, ecogeographic mapping, and the establishment of Documentation Cell as a part of Center of Excellence. The project outputs of the Component on Documentation of FGR have been broadly described in the following three sub-components:

16.9.1.1

Species Profile, Distribution and Status

Total 5,290 nested quadrats were laid across 37 forest sub-types and 39 forest divisions/ PAs/ wildlife divisions covering an extent of 0.529 km^2 representing 0.002 per cent of cumulative forest cover of 37 forest sub-types for the purpose of varied assessments on prioritized FGR species. The target of documenting 250 prioritized FGR species representing 88 plant families and comprising 180 tree, 47 shrub, and 23 woody climber species including 62 RET species by describing the species profile with an updated nomenclature, synonyms, local names, uses, threats, distribution within Uttarakhand and across different forest sub-types and forest divisions, population structure, and regeneration status was fully achieved and has been presented in a featured template customized for the purpose. Plant families *viz.*, Fabaceae, Lauraceae, Moraceae, Berberidaceae, Rosaceae, Euphorbiaceae, and Betulaceae collectively covered almost 28 per cent prioritized FGR species.

Priority Forest Sub-Types: Four prominent forest sub-types *viz.*, Upper or Himalayan Chir Pine Forest, Ban Oak Forest, Moist Shiwalik Sal Forest, and Northern Dry Mixed Deciduous Forest out of 37 forest sub-types assessed for diversity of prioritized FGR species emerged as the most important forest sub-types from the perspective of conservation as they harboured disproportionately higher number of diverse FGR species. Among 146 prioritized FGR tree species, four species *viz.*, *Quercus leucotrichophora, Pinus roxburghii, Ficus semicordata*, and *Grewia optiva* were widely distributed as their presence was recorded in as many as 13 forest sub-types in each case.

Important Forest Divisions: The highest number of 115 FGR species were recorded in Pithoragarh FD, because it is the largest division and represents extremes of altitudinal gradient besides high extent of forest cover under three different forest canopy classes. Pithoragarh FD was followed by Mussoorie FD, Ramnagar FD, Uttarkashi FD, Dehra Dun FD, Champawat FD, Bageshwar FD, Rudraprayag FD and

Terai East FD registering distribution of 99, 85, 82, 79, 78, 72, 71 and 68 prioritized FGR species, respectively.

Regeneration Status: The project significantly contributed towards the current status and baseline information on the regeneration status of 250 FGR species and also offered deep insight towards the performance of individual species as well as 37 forest sub-types wherein regeneration studies were carried out. The cumulative 644 assessments in case of prioritized FGR species revealed good, fair, poor, no and new regeneration in 65.5 per cent, 13.81 per cent, 16.92 per cent, 2.95 per cent, and 0.77 per cent, respectively. In case of 146 FGR tree species, good, fair, poor, no, and new regeneration was observed in 80.64 per cent, 12.40 per cent, 4.71 per cent, 1.98 per cent and 0.24 per cent of overall assessments, respectively. All 62 RET exhibited poor regeneration and this situation demands high management attention and interventions.

Use of FGR Species: Almost 68.8 per cent species were found to have medicinal importance. 112 species (44.8 per cent) are used for fuelwood followed by 43.2 per cent prioritized FGR species which find multiple uses. Nearly 32.8 per cent species are used for fodder. Fruits of 52 species (20.8 per cent) are being used for direct consumption or in production of squash/juice. About 18 per cent studied species have importance as timber or are being used for making turnery articles and furniture, while 8 species are being used in charcoal making.

Threats to FGR Species: A larger proportion (58 percent) of prioritized FGR species face threat on the account of varied developmental activities, particularly expansion of road and railway network and widening of existing highways, execution of hydropower projects, and increasing infrastructure related to tourism. As many as 51 species or about one-fifth of prioritized FGR suffer on the account of genetic erosion caused by change in land use, over harvest, recurrent forest fires, livestock grazing, habitat loss and fragmentation, scattered small populations, and disruption in gene flow. At least ten species were at risk on account of overexploitation for medicinal purposes.

16.9.1.2

Modernization and Digitization of DD Herbarium

Well known herbaria across the globe have been recognized as important repositories of plant specimens, having notable contribution towards the documentation of FGR species. The forest-based herbarium with ca. 3,30,000 plant specimens housed in the campus of FRI, Dehra Dun is one of the oldest herbaria, known as the DD Herbarium. It 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. 1000 specimens besides it holds an estimated 1,300 Type Specimens and historically important collections from various expeditions. An herbarium is more than a mere collection of dried specimens, but these specimens tell stories beyond the plants themselves-about how a specimen have languished for decades in obscurity until botanists with a keen eye recognized it as a new species or other allied professionals use them in phenological research or studying the impact of climate change. However, several old herbaria and their invaluable collection are vulnerable to anthropogenic as well as natural calamities. Moreover, such collections are a valuable record of existing biodiversity across the globe and through time and space. The digitization of herbaria has emerged as a global enterprise so as to facilitate easy access and remote consultation of precious collection, faster retrieval of specimens and relevant information, and their potential use in modern research pertaining to conservation of FGR, plant systematics, ecogeographic distribution, phenology, impact of climate change, etc.

The Pilot Project made notable contribution towards renovation of DD Herbarium 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 financed under the 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.

16.9.1.3

Ecogeographic Mapping of Prioritized FGR Species

In biology, the geographical area within which a species can be found has been referred as the 'range of a species'. It includes natural or native range, where it has originally originated and lived, and the range where a species has more recently established. Ecogeographic studies have been defined as 'the process of collecting, characterizing, systemising different kinds of data pertaining to target taxa within a defined region', and they can contribute vital information on plant/ forest genetic resources so as to assess their conservation status and identify priority areas for conservation. A wide range of species distribution and predictive models exist today, helping in providing the valuable insight on ecogeographic distribution of target taxa and identification of bioclimatic variables responsible for the occurrence and distribution of the species. In the Pilot Project, the 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 helped in generating GIS based ecogeographic maps of range and population distribution of 37 prioritized FGR species. The MaxEnt prediction accuracy is always stable and reliable, particularly in a situation when there are fewer presence data and small sample sizes. It reduces the amount of effort required in the inaccessible, rugged terrain, difficult field situations, and harsh climatic conditions. The outputs generated reduce cost and improve management efficiency.

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 owing to their smaller number of geo-coordinates. Ecogeographic maps 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, and other specific information for each species generated through modeling. The ecogeographic maps 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 offered 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.

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 (> 250 km^2). In contrast, species *viz., Albizia julibrisin, Hovenia dulcis, Corylus jacquemontii, Olea europaea*, and *Ulmus wallichiana* had lower extent of their distribution range varying from 33.49 km^2 to 78.98 km^2. In case of remaining 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*). Districts *viz.*, Pithoragarh, Uttarkashi, Nainital, Bageshwar, Champawat, Dehra Dun and Pauri recorded relatively higher number of species. 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.

16.9.2

FGR Seed and Germplasm Storage

Germplasm provides the essential hereditary material to natural resource managers dealing with varied aspects of forest management, particularly raising nurseries, and plantations besides tree improvement. 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. Seeds are the most common and convenient materials specially 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. The objective for seed storage is primarily either short term for forestry operations or long term for germplasm conservation.

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 contrast to agricultural crop plants, production, transportation, and storage of seeds in case of FGR species is difficult as they are long lived, often produced in small quantities, and generally have limitations on account of their sensitivity to desiccation, long term storage and germination behaviour. Despite this, 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. Thus, the Pilot Project envisaged to demonstrate that seeds of FGR species can be stored for periods well in excess of the time to reach reproductive age and preferably the tree's lifespan. 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.

Plant Tissue Culture (PTC) or *in vitro* culture has emerged as an appropriate alternative method for conservation of germplasm. PTC has been defined as the process in which plant cells, tissues, organs or any parts thereof are grown in aseptic conditions in an artificial environment. PTC has been employed in the context of several broad classes of plants: (a) species that are only propagated vegetatively; (b) species taking a long time for production of seeds and having long life cycles; (c) species with recalcitrant and desiccation sensitive seeds; (d) species having sterile individuals or even producing empty seeds; (e) propagules that need to be collected beyond the seed shedding season; and (f) species requires disease elimination for successful conservation and subsequent propagation.

Pollen grain represents the male gametophyte of any plant, and it is either dispersed by wind or insect to the receptive stigma. Viable pollens germinate and extend pollen tubes to facilitate movement of male gametes for fertilization within the ovary. For a successful fertilization event, viability of pollens is a crucial factor and inability to germinate leads to poor seed set and may affect the population of a species. Pollen is a useful source of diverse alleles within a gene pool and thus, an effective propagule for gene banks. Pollen culture has been developed as an *in vitro* technique, in which haploid plants are collected from isolated pollen grains while in anthers. They are cultured by placing anthers on a suitable, synthetic culture medium. Progeny developed by this technique contains a single set of chromosomes. The ease of pollen storage and shipment and the potential for its immediate use have opened wide array of avenues in diversification and propagation of a species in its natural environment. Hence, pollen conservation is an important tool for the maintenance of plant genetic resources and can promote improved efficiency in breeding programs and germplasm conservation and exchange.

In view of the above, the Pilot Project envisaged the development of protocols for medium to long term storage of seeds, and other germplasm material.

16.9.2.1

Protocols for Seed Storage of Prioritized FGR Species

The task specific to seed storage of prioritized FGR species included development of protocols for seed extraction, processing, quality testing methods for medium- and long-term storage for prioritized FGR species. Twenty-five FGR species in the demonstration state 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 by availing the facility of National Bureau of Plant Genetic Resources (NBPGR), New Delhi. Accordingly, FRI and NBPGR have signed a Memorandum of Agreement (MoA) in 2016 for the purpose of collaboration and seed storage of prioritized FGR species in the facility of the latter.

Seed production has a major role in the dynamics of a forest ecosystem. Seed germination, sapling and seedling stages are crucial processes in the development of natural forest communities. Knowledge of the natural regeneration associated with seed quality and seed production are important for developing scientific models, techniques, and new management guidelines to conserve the dwindling natural forest areas. The field observations and laboratory investigations on seed collection, and germination revealed the following major concerns regarding tree species in their natural forests which have potential impact on regeneration, forest structure, composition, functions, and succession.

(a) Seed Biology: Emptiness in seeds was one of the major issues observed in several species. It is associated with pollination - fertilization failures. Early and immature seed fall was also observed in many species. Incomplete development and partially filled seeds were also observed in species that may be associated with environmental factors e.g., *Acer caesium, Premna mollissima, Pittosporum napaulense, Kydia calycina, Anogeissus latifolia*, and *Buxus wallichiana*.

(b) Seed Dormancy: Deep dormancy in seeds causes regeneration delay, at times failure in nature due to long time requirement for breaking dormancy in the soil seed banks e.g., *Cinnamomum tamala, Corylus jacquemontii* and *Betula utilis*.

(c) Fungal and Insect Pest Infestation: Seed borne pathogens, especially fungi are associated with seeds of several species. Insect injuries were also observed in several species. Seed-borne fungi and insect-pests reduced the quality of seeds. Pathogens infested during seed development, storage, or germination resulted into seed damage by way of loss of seed viability or from seedling infection following germination e.g., *Albizia odoratissima, Dalbergia lanceolaria, Albizia julibrissin* and *Cordia dichotoma*.

(d) Anthropogenic Pressure: Immense anthropogenic pressure was observed on species having socio-economic utility and multiple values. Lopping associated with fodder collection for livestock, fuelwood collection, timber value of species, medicinal uses, edible parts, etc. determined the biotic pressure on the species e.g., *Cinnamomum tamala, Piliostigma malabaricum, Sterculia villosa, Stereospermum, Flacourtia indica, Schleichera oleosa*, etc.

(e) Population Status of Species: Isolated populations, scattered populations, and population decline were observed in several species which are socio-economically and ecologically important, RET categories, and Lesser-Known Tree Species (LKTS) e.g., *Bauhinia malabarica, Corylus jacquemontii, Premna mollissima, Acronychia, Boswellia serrata, Toona serrata, Celastrus paniculatus, Buchanania cochinchinensis*, etc.

Studies on the development of seed storage protocols for *ex situ* conservation of seed germplasm under medium-and long-term storage conditions revealed that seeds of FGR species under medium term storage condition may be grouped into the following three categories based on their initial viability:

(a) Initial Seed Viability >60 Per Cent: Several tropical and sub-tropical species such as *Acacia catechu, Aegle marmelos, Albizia julibrissin, Aristolochia elegans, Berberis lycium, Bischofia javanica, Dalbergia sissoo, Ougeinia oojeinensis, Fraxinus micrantha, Hippophae salicifolia, Holoptelea integrifolia, Oroxylum indicum, Picea smithiana*, etc. had initial viability greater than 60 per cent. All these species maintained their initial viability at hermetic storage condition at 5°C storage temperature and reduced seed moisture content, except Ougeinia oojeinensis which lost its viability in two years in the given storage conditions.

(b) Initial Seed Viability between 30 to 60 Per Cent: FGR species such as *Carpinus viminea, Juglans regia, Kydia calycina, Myrica esculenta, Rhamnus triquetra* and *Pyrus pashia* exhibited initial viability between 30 to 60 per cent. However, these species were successfully conserved without losing initial viability for more than a year in hermetic condition at 5°C storage temperature.

(c) Initial Seed Viability <30 Per Cent: *Celtis tetrandra* and *Punica granatum* had less than 30 per cent germination percent after pre-treatments and could be successfully stored at hermetic condition at 5 °C storage temperature for medium term.

Pinus wallichiana, Oroxylum indicum, Dalbergia sissoo, Acacia catechu and *Hippophae salicifolia* exhibited high storage possibility under medium storage conditions by retaining viability at almost initial levels for more than 3 years. Hence, present study recommended to conserve those species which maintain initial viability for long durations into the long-term conservation unit after preliminary viability test and minimum required moisture level to maintain the metabolic activity of seed.

The present study also divided seeds into four categories based on initial viability, germinative capacity and storage potential under medium term storage conditions at 5°C *viz.*, (a) seeds having high initial viability and good storage potential e.g., *Oroxylum indicum* and *Hippophae salicifolia*; (b) seeds having high initial viability and less storage potential e.g., *Ougeinia oojeinensis*; (c) seeds having low initial viability and good storage potential like *Carpinus viminea*; and (d) seeds having low initial viability and low storage potential e.g., *Juglans regia*. The study recommended that the present categorization can be correlated with the natural regeneration status of species associated with seed quality and seed production status which may help to devise some valuable strategies for future conservation of such species. The major challenges where species requires special attention in the field like biotic pressure, fungal and insect infestation, population status, seed dormancy and seed biology need to be appropriately addressed along with laboratory-based research activities.

As envisaged, seeds of 100 targeted FGR species from different sources in Uttarakhand have been conserved in the Seed Bank of ICAR-NBPGR. The leads and knowledge generated through the Pilot Project has opened enormous avenues for similar efforts and programs for implementation in other States/ UTs of the country.

16.9.2.2

Tissue Culture Protocols for Important FGR Species

Biotechnological strategies such as in vitro growth or tissue culture as stated above has emerged as one of the best alternatives to address issues associated with germplasm conservation in field conditions, particularly in case of problematic seeds. Pilot study on select eight species *viz.*, Trees - *Albizia julibrissin, Dysoxylum gotadhora, Ougeinia oojeinensis, Oroxylum indicum*, and *Hymenodictyon orixense*, and Shrubs - *Aristolochia punjabensis, Catamixis baccharoides*, and *Hippophae salicifolia* for the purpose of development of micropropagation protocols through seeds/ nodal explants; and additional two species *viz.*, Tree- *Diploknemma butyracea*, and Shrub- *Meizotropis pellita* species used for the development of callus regeneration pathways revealed the following:

- In case of problematic species on account of seeds, the most advanced method of genetic resources conservation is to keep them in a laboratory setting. Plant parts can be kept alive under controlled laboratory conditions, proving that every part of the plant can develop into a whole organism. One of the main reasons behind the conservation of genetic resources is that it maintains biodiversity and provides a validated genetic resource in both genotypic and phenotypic aspects.
- Storage behavior of the species involved, applicability of the methods chosen for storage and their cost-effectiveness are some of the crucial parameters that are required to be kept in mind while devising such conservation methods.
- Present study aimed at highlighting different techniques of medium-term storage for conserving valuable forest genetic resources. Methods such as encapsulation of plant sections, growth under limiting conditions, use of ethylene inhibitors and extension of subculture duration elaborated could be utilized in framing strategies for germplasm conservation.

- Alginate encapsulation is a valuable technique that can prove to be cost effective in transportation of propagules as well as addressing issue of limited storage space. However, method optimizations are required to achieve efficient short-term storage through manipulating storage conditions and encapsulation reagents.
- In case of rapid decrease in regrowth percentages, long term storage methods utilizing dehydration (physical or chemical) and cryopreservation (exposure to liquid nitrogen) techniques can be applied. Successful conditions or medium applied varied with the species investigated in present study, so this is suggested that for all species, specific treatments for regeneration and medium-term storage protocols should be developed. For example, artificial seed is successful with easily regenerating species like *Aristolochia punjabensis* and *Albizia julibrissin* and can also be stored for long term in ultralow temperature under liquid Nitrogen condition.
- Long duration subculture maintenance in a vessel was found to be a cheaper and useful option for alpine species like *H. salicifolia* where single culture cycle could be maintained for six months. Osmoprotectants also showed promising result in many species as this has checked the dehydration of the stored tissue.

The study amply highlighted that in vitro storage methods are an effective tool to store propagules of RET and recalcitrant species for medium term.

16.9.2.3

In Vitro Pollen Germination and Storage of Selected FGR

The sub-component of the project on pollen storage focused on several lesser studied forest tree species which have conservation as well as economic significance for study on pollen germination ability under *in vitro* conditions along with their storage under cryogenic conditions. The experimental material included flower buds of varied FGR species *viz., Rauvolfia serpentina* and *Alstonia scholaris* (Apocynaceae); *Meizotropis pellita* and *Sophora mollis* (Fabaceae); *Heteropanax fragrans* (Araliaceae); *Oroxylum indicum* (Bignoniaceae); *Diploknema butyracea* (Sapotaceae); *Sterculia colorata* (Malvaceae); *Crateva adansonii* (Capparaceae); *Mahonia jaunsarensis* (Berberidaceae); *Falconeria insignis* (Euphorbiaceae); and *Buxus wallichiana* (Buxaceae). The study generated important information about the *in vitro* growth requirements of pollen grains in these species and imparts leads towards long term storage of forest germplasm in the form of pollens.

Knowledge of pollen germination ability and their longevity under storage conditions can help frame methods for controlled pollination and related studies. The study has provided information on several species with protocols to understand behaviour of different pollens under *in vitro* conditions.

It was observed that although pollen viability at the start of experiment was higher, it reduced to much lower levels after three months of storage in liquid nitrogen. Storage of germplasm in the form of pollens becomes useful in species where irregular flowering, asynchronous development of male or female flowers, or production of non-viable pollens are major problems in successful seed set. In such cases, if pollens could be stored for long term under viable conditions, controlled pollination or other related studies can be attempted at any time of season. Availability of such methods is also useful for management and conservation of valuable FGR. Overall, conservation of germplasm in the form of pollens offers an interesting approach that not only allows preservation of diverse pollen grains but is also a good opportunity to study different cellular processes such as cell growth, cell wall formation as well as intracellular transport in a single cell system.

16.9.3

FGR Characterization

Evaluation process of a species for identifying and describing features or traits of individuals and populations *viz.*, morphology, phenology, chemical content, resistance or susceptibility to pathogens, genetic constitution, etc. is referred as characterization, as it seeks to provide essential and prerequisite information for the conservation of a species. Characterization enables in developing an understanding on the nature of FGR by way of appreciating the threats it faces and the potential (uses, productivity, economic, adaptive, evolutionary, etc.) it may hold. Characterization is undertaken at two levels: firstly, at the species level across its whole distribution range, and secondly at the level of the stand or population. Characterization at the population level helps in identification of ecologically/ economically superior populations over the entire distribution range of the species. Current understanding on linkages among varied insight arising from multi-disciplines is tenuous and, therefore, full integration is needed.

Under this Component of the project, the biochemical characterization focused on secondary metabolites, specifically phenolic compounds including flavonoids besides terpenoids, particularly triterpenoids, and 10-deacetylbaccatin III (10DBA-III), a tetracyclic diterpenoid and a secondary alpha-hydroxy ketone.

Molecular characterization in case of wild species or their natural populations is an important step as it determines the genetic variability existing within (intraspecific) and among the populations (interspecific) of the species. Molecular Characterization is a broad term that refers to using molecular markers, including DNA, RNA, and proteins, to determine the genetic characteristics of cells or tissues. Generally, genetic variability is being characterized for two primary purposes: (a) conservation planning and sustainable forest management based on identification of 'genetic diversity hotspots' rich in unique alleles; and (b) breeding and improvement of a species based on identification of superior genotypes.

Forest pathogens, predominantly fungi are amongst the most known and obvious threat to forest health, with their impacts amplified by enhanced biotic disturbances, climate change and global trade. Enhanced frequency and severity of pathogen infestations, particularly fungal diseases have led to the loss of significant forest areas, plant vigour and reduced productivity. Varied fungal species could be associated with different plants and vary with respect to the geographical locations and plant parts. Fungi cause seed rots, seedling damping-off, root rots, foliage diseases, cankers, vascular wilts, die-backs, galls and tumors, trunk-rots, and decay of ageing trees, and they may result into catastrophic losses in the event of an outbreak of a disease. Thus, pathological characterization of ecologically and socioeconomically valuable tree species by recording fungal species associated with them is of utmost importance.

As a part of the Pilot Project, biochemical, molecular, and pathological characterization of five prioritized tree species *viz., Betula utilis, Myrica esculenta, Quercus semecarpifolia, Rhododendron arboreum*, and *Taxus wallichiana* was undertaken. Major revelations based on characterization of the target species are as follows:

16.9.3.1

Biochemical Characterization

In search of chemically superior populations for ex situ conservation and mass multiplication, chemical characterization of above stated five medicinally valued tree species growing across diverse forests of Uttarakhand based on assessment of stem bark of 11 populations of *B. utilis*, and 11 populations of *M. esculenta*; leaves of 14 populations of *Q. semecarpifolia*; flowers of 09 populations of *R. arboreum*; and needles of 15 populations of *T. wallichiana* for their total triterpenoid contents (TTCs), total phenolic contents (TPCs), total flavonoid contents (TFCs) and 10-Deacetylbaccatin III (10-DAB III) contents was undertaken because of their medicinal/ biological/ pharmacological effects. Analysis showed significant variability in contents of TTCs, TPCs, TFCs and 10-DAB III across sampled populations. Further, analysis led to grouping of the populations of *B. utilis, M. esculenta, Q. semecarpifolia, R. arboreum* and *T. wallichiana* in 6, 4, 3, 4 and 4 clusters, respectively, indicating a close relationship between populations within the same cluster. The study helped in identifying populations of *B. utilis* located in Niti, Himkhola, Dharchula, Har ki Doon, and Darma Valley; *M. esculenta found* in Kausani and Takula; *Q. semecarpifolia* grown in Yamunotri and Radi Top; *R. arboreum* located in Budher and Chaurangi Khal; and *T. wallichiana* found in Deoban, Harshil, Ghes, and Har Ki Doon as chemically superior populations based on their respective highest biochemical contents, and they have been recommended for conservation and mass multiplication.

16.9.3.2

Molecular Characterization

Maintenance of genetic diversity is one of the main objectives of conservation programs which aims at maximizing either expected heterozygosity or allelic diversity. Maximization of allelic diversity has been reported to be more efficient in maintaining the genetic diversity of subdivided populations than maximization of expected heterozygosity because the former maintains a larger number of alleles and better control of inbreeding. Hence, the populations with higher allelic diversity and private alleles deserve higher priority for conservation programs.

All the five studied Himalayan tree species showed high genetic diversity indicating their high adaptive and evolutionary potential. Following 28 genetic diversity hotspots identified in case of five targeted species based on their molecular characterization, particularly allelic richness and presence of unique alleles will serve as the guiding principles for the future conservation programs and these genetic hotspots have been recommended for the establishment of prioritized in situ conservation sites among sampled populations as the Forest Gene Conservation Units (FGCUs):

(i) ***Q. semecarpifolia*** - QS09 (Radi Top, Upper Yamuna Barkot FD), QS11 (Bhukkitop, Uttarkashi FD), QS15 (Munsiyari, Pithoragarh FD), QS19 (Mundhola, Chakrata FD), QS21 (Pinswar, Rudraprayag FD), QS23 (Narayan Ashram, Pithoragarh FD), and QS24 (Himkhola, Pithoragarh FD)

(ii) ***M. esculenta*** - ME08 (Sandev, Pithoragarh FD), ME15 (Takula, Almora FD), ME16 (Shitla Khet, Almora FD), ME17 (Bhowali, Nainital FD), and ME18 (Mayali, Rudraprayag FD)

(iii) ***T. wallichiana*** - TW12 (Mundhola, Chakrata FD), TW15 (Himkhola, Pithoragarh FD), TW18 (Mornaula, Nainital FD), TW19 (Har ki Dun, Govind WLS and NP), and TW21 (Baling, Pithoragarh FD)

(iv) *B. utilis* - (BU01 (Rudranath, Kedarnath WD), BU06 (Himkhola, Pithoragarh FD), BU10 (Triyuginarayan, Rudraprayag FD), and BU11 (Darma Valley, Pithoragarh FD)

(v) *R. arboreum* - (RA11 (Chaurangi Khal, Uttarkashi FD), RA16 (Dunagiri, Almora FD), RA18 (Chirbatiya, Tehri FD), RA19 (Badhanital, Rudraprayag FD), RA22 (Dhanaulti, Narendranagar FD), RA23 (Ghes, Badrinath FD), and RA24 (Gwaldam, Badrinath FD)

Above recommended 28 FGCUs will ensure the maintenance of high genetic diversity among five targeted species, and the genetic diversity on these hotspots need to be taken into consideration for any type of *ex situ* conservation measure including germplasm storage, rescue of inbred populations or even the production of starting material for propagation.

In each of the five studied FGR species, some populations with unique set of private alleles have been identified. If such populations continue to deteriorate, the rare alleles contained in them would gradually be lost. Thus, such identified populations with unique alleles need utmost conservation attention by way of: (a) effective protection and *in situ* conservation of such populations; and (b) augmentation of small populations in such cases by reforestation and enrichment planting using their own germplasm to maintain their unique characteristics based on private alleles.

Two important genetic processes of natural populations *viz.*, genetic differentiation and gene flow have been recognized, and these processes are inversely related but controlled by multitude of factors related to the species and geographical distribution range. Among five targeted species, moderate level of genetic differentiation and structuring were recorded in *Q. semecarpifolia* due to strong physical barriers imposed by the mountain ranges and river systems of western Himalayas leading to the emergence of two distinct gene pools (GHC- Greater Himalayan Conservation, and MHC- Middle Himalayan Conservation gene pools) which need to be maintained as independent reservoirs of alleles to conserve the genetic diversity captured within them in the long run. In the remaining four investigated species, sufficient gene flow has been maintained to counter the effect of genetic differentiation due to outcrossing and contiguous distribution range over large geographical span.

Study detected significant genetic structuring in the populations of *Q. semecarpifolia*, *B. utilis*, and *R. arboreum*, and therefore, conserving any random population of these species within the State will not serve the conservation purpose. Thus, seed or planting material must be collected from diverse populations identified in each genetic cluster for the establishment of *in situ* FGCUs, as well as *ex situ* Field Gene Banks (FGBs). Further, in case of three high altitude species (*B. utilis*, *Q. semecarpifolia*, and *T. wallichiana*), the populations present in Pithoragarh FD, particularly Darma Valley and Narayan Ashram in Dharchula forest range emerged as the most important reservoirs of allelic diversity and need to be considered at top priority in conservation programs.

16.9.3.3 Pathological Characterization

Alternaria spp., *Fusarium* sp., and *Nigrospora sphaerica* were recorded for maximum number of times causing foliar diseases with disease intensity of upto 45 per cent, followed by *Phomopsis* sp., *Pestalotiopsis* and *Curvularia* spp. on the tree species. These foliar pathogens tend to be deeply influenced by weather, and their sporulation and infection are affected by change in climatic conditions as they often occur within a narrow range of temperature and their spore release usually coincide with periods of precipitation and regions of wet winters. *Ganoderma* spp. (*G. applanatum* and *G. lucidum*) were also found frequently causing heart and root rot, thus leading to death of the trees.

Fungi have been recognized as capable of creating high biodiversity within short time span as compared to their hosts including plants due to shorter time duration of the life cycle and multiplication, the evolutionary changes and adaptation to newer climatic conditions and hosts. Several factors are considered responsible for the emergence of newer pathogens of host tree species, particularly at higher altitude on account of frequent weather fluctuations.

Study on pathological characterization yielded valuable baseline information on the association of different fungal species with respect to five targeted FGR species. Amongst sampled populations, eleven populations for *R. arboreum*; ten populations for *Q. semecarpifolia*; nine populations for *T. wallichiana;* twelve populations for *M. esculenta*; and five populations for *B. utilis* were found healthy and superior for *in situ* conservation.

The future disease surveys and a comparison with the baseline information generated through the present study will help in providing a valuable insight regarding the spread of the existing diseases or incidences of newer health problems of five studied tree species.

Enhanced green-house gases are likely to upset the nutritional uptake of trees, resulting in nutritional deficiencies especially with respect to micronutrients which could become a limiting factor for the tree health and growth. Such nutritional imbalances may affect the tree vigour adversely and offer favourable conditions to pathogens. Changing field scenario due to varied environmental factors demands monitoring of soil status for effective mitigation of pathological problems.

16.9.4

FGR Conservation

Forests harbour a wide range of native, non-native, and naturalized forms of tree species which have adapted in different ways to their growing environments. Forests and associated biodiversity are under intense stress, and due to this, several FGR species persist as small, semi-natural, and fragmented populations. Efforts are underway to reverse the effect of forest degradation through reforestation, afforestation, and even plantations outside forests, and to cater the growing demand for wood, fuelwood, and a wide array of NTFPs. Broadly, dynamic *in situ* and static *ex situ* approaches are in practice for the conservation of biodiversity including FGR. Most governments and local communities have launched a variety of programs for the conservation of natural and semi-natural forests. In addition, forest remnants/ planted forests in the human modified rural landscapes dominated by agricultural crops have been recognized as an important element of *circa situm* conservation as these remnants/ planted trees are not only repository of biodiversity but also offer enormous values (as habitats, pollination, seed dispersal and germination, subsistence, livelihood, and environmental amelioration) besides vital connectivity for PAs/ MFs, and even FGR species. Varied forestry conservation practices, often require production of genetically improved starting material and propagation methods and thus, they are largely derived from high quality superior identified seed and plant sources.

The Component on FGR conservation specifically envisaged production of starting material of important tree species, standardization of propagation techniques of five prioritized tree species, establishment of FGCUs based on identification of genetic diversity hot spots, FGBs, development of an understanding on *circa situm* repositories and the role played by protected areas towards conservation of FGR.

16.9.4.1

Production of Starting Material and Standardization of Propagation Techniques

The forest tree species may be multiplied in the nursery using seeds, branch cuttings, root cuttings, or air layering. The plants thus raised may be planted in the field for carrying out afforestation, reforestation, enrichment planting, and for establishing gene banks or conservation areas. Private or community plantations may also be established using the plants. Differences in propagation success of a given species may vary with population being propagated, however, the variation is expected to be within a range of 10 to 15 per cent only. As a part of the Pilot Project, study on the standardization of propagation techniques through seed, branch cutting, and air layering in five priority tree species *viz., T. wallichiana, R. arboreum, M. esculenta, Cinnamomum tamala*, and *Diploknema butyracea* revealed varied levels of difficulty in propagation of the studied species.

The study recognized branch cutting as the best method for propagation of *T. wallichiana*, followed by air layering with success rate of 70-77 per cent and 35-40 per cent of plants, respectively. In case of *R. arboreum*, the best recommended method recognized was of air layering with 38-60 percent survival, while propagation through seeds and root cuttings resulted in 9-25 per cent and 7-27 per cent survival, respectively. Propagation by seeds in case of *M. esculenta* yielded relatively better performance than the branch cutting with corresponding values of 26-30 per cent and 10-13 per cent success rate, respectively. In case of *C. tamala*, propagation by seeds revealed 67-69 per cent survival, while the air layering method could ensure only 45-57 per cent success. Propagation by seeds as well as branch cuttings in case of *D. butyracea* emerged as the most preferred propagation methods as they showed 85-90 per cent and 55-60 per cent survival, respectively. In general, seeds can be easily employed in case of four targeted species except *T. wallichiana* besides above recommended vegetative propagation methods. Planting material from seeds is likely to have greater genetic diversity than that from vegetative propagation. Thus, as far as possible seeds may be preferred for establishing FGCUs and FGBs. The Pilot Project recommended that non-mist propagation chambers are cheaper than mist chambers, and they can be installed in places where it is not possible to install the conventional mist chambers due to concerns of high cost. They are also effective in providing suitable environment for vegetative multiplication of tree species through cuttings, especially in case of dioecious trees of *T. wallichiana* as seeds of this species are not easily available.

16.9.4.2

Establishment of FGCUs and FGBs

The characterization of five targeted tree species, particularly at the molecular level distinctly provided valuable insight on genetic diversity hotspots in each case based on their allelic richness and presence of rare alleles. The above section 16.9.3.2 has already provided details on 28 genetic diversity hotspots and recommendations for the establishment of corresponding FGCUs. The study has aptly highlighted that the concept of identification of hotspots based on genetic characteristics in the context of FGR species and their *in situ* conservation is new for India. However, for past decade or so, the European countries and EUFORGEN have been advocating for *in situ* conservation of genetic diversity hotspots and have been successful in implementing the establishment of a network of *in situ* gene conservation units. The UK Forestry Commission has not only provided the criteria for the establishment of field level gene conservation units but have also elaborated on the prescriptions to be followed for their management. Availing the benefit of this rich experience, the Pilot Project has recommended for the establishment of 28 FGCUs and provided their broad-based management prescriptions. Details on each recommended FGCU in terms of the geo-coordinates, compartment, beat, range, and forest division besides name and code of the sampled population have been incorporated in the concerned Chapter. Similar details of six FGBs established in case of *R. arboreum*, *M. esculenta*, *T. wallichiana*, *D. butyracea*, *C. tamala*, and *Toona ciliata* in the State besides sources of seeds/ germplasm, type of design (RBD or ABD), spacing, and number of plants have also been provided in the concerned Chapter.

16.9.4.3

Circa Situm Conservation

The role of *circa situm* conservation, especially in human dominated forest and rural landscapes in India when such areas are experiencing varied challenges on account of enhanced biotic and developmental pressures is vital in conservation of threatened FGR. The preliminary pilot study in select 20 villages in Garhwal and Kumaon regions has amply revealed that as many as 19 FGR species are being conserved in *circa situm* repositories by local communities, and efforts are needed not only to develop a database on such forest remnants but awareness about the need of their conservation is required to be created besides replicating similar studies in much more representative villages/ landscapes across the altitudinal gradient.

16.9.4.4

Role of PAs in FGR Conservation

The State has a network of seventeen PAs including six National Parks, seven Wildlife Sanctuaries, and four Conservation Reserves besides a vast extent of Managed Forests across the altitudinal gradient and other conservation management areas set aside for conservation of biodiversity, especially charismatic, flagship, and RET species helping in the continuance of ecosystem services; maintenance of ecosystem; species and genetic diversity; and contribution to the sustainable development goals.

The concerned Chapter has provided an insight on phytosociological assessment in three PAs (Rajaji Tiger Reserve, Nandhaur WLS, and Mussoorie WLS) and how different forest type groups in these reserves are able to retain the diversity of FGR species. Three PAs were represented by five Forest Type Groups. Amongst them, the Tropical Moist Deciduous Forests and Tropical Dry Deciduous Forests were important in harbouring the wider diversity of FGR.

In addition, the potential ecogeographic mapping in the context of 50 prioritized FGR species also offered valuable information and insight with respect to the extent coverage of their distribution range within the PA network. Out of 50 FGR species, ecogeographic mapping based on the MaxEnt Modeling using long-term database on bioclimatic variables besides presence data on the species was carried out, while in case of remaining thirteen species, localized ecogeographic mapping was possible due to their scant distribution and small population size. Out of 37 species, only 35 FGR species showed potential ecogeographic distribution in PAs. The values of estimated ecogeographic distribution area in case of 35 species ranged from as low as 2.10 km^2 to 283.59 km^2 in case of *Diploknema butyracea* and *Betula utilis*, respectively. Two species *viz.*, *Olea europaea* and *Premna mollisima* have shown no predictive distribution within PAs. Amongst five prioritized FGR species selected for characterization, *M. esculenta* with 0.75 per cent representation within PAs registered the lowest value, while *B. utilis* obtained the highest value of 92.93 per cent. Remaining three species *viz.*, *Q. semecarpifolia*, *T. wallichiana*, and *R. arboreum* obtained values of ecogeographic distribution within PAs *viz.*, 21.99%, 27.67%, and 14.9%, respectively. In case of 13 FGR species, the estimated localized ecogeographic distribution revealed that as many as six species have not shown any estimated distribution within PAs. Species like *Boswellia serrata* has bulk (99.75 per cent) of its ecogeographic distribution within PAs, while species like *Madhuca longifolia* having enormous socioeconomic importance registered a lower extent of just 29.75 per cent.

The predictive ecogeographic mapping in case of prioritized FGR species amply reflected that several FGR species have their substantial distribution outside PAs, mainly in managed forests or even *circa situm* conservation repositories in rural/ agricultural landscapes. Hence, it is essential that PAs, MFs and other conservation areas are considered together as interdependent entities in a wider landscape. The Ecosystem Based Forest Management (EBFM) or landscape approach to conservation is more relevant in the case of Himalayan State.

Uttarakhand is privileged to have two important and prominent Tiger Reserves i.e., Corbett and Rajaji out of total 52 TRs in the country. Out of 16 major Forest Type Groups, the ISFR-2021 reported occurrence of four Forest Type Groups each in CTR and RTR. In case of Corbett TR, Group 3 - Tropical Moist Deciduous Forest was the dominant type and was represented by an extent of 994.43 km^2 forest cover. This was followed by 223.67 km^2 of Group 5 - Tropical Dry Deciduous Forest. Two other forest type groups namely Group 9- Sub-Tropical Pine Forests and Group 12 - Himalayan Moist Temperate Forests covered an extent of 3.65 km^2 and 0.01 km^2 forest cover, respectively. Like Corbett TR, the Rajaji TR also had the maximum extent of forest cover, being 507.45 km^2 in case of Tropical Moist Deciduous Forest, followed by Tropical Dry Deciduous Forest represented by forest cover of 444.10 km^2. Sub- Tropical Pine Forest registered a small extent of forest cover of 1.76 km^2. Instead of the Himalayan Moist Temperate Forests in case of CTR, the RTR had a small extent (0.76 km^2) of Group 4 - Littoral and Swamp Forests. Five different Forest Type Groups represented in two well protected TRs covering a cumulative extent of about 2,150 km^2 forest cover under three forest canopy density classes certainly harbour a wide array of FGR species. Hence, these two TRs besides other PAs significantly contribute not only towards conservation of floral and faunal diversity but also in the maintenance of genetic diversity within FGR species. The ISFR-2021 revealed that both TRs in the State showed decline in forest cover by 29.91 km^2 (Corbett) and 30.20 km^2 (Rajaji) during the decadal period (2011-2021). These two TRs were among the list of 32 TRs in the country which have shown slight decline in Forest Cover during the decadal period despite comprehensive and multipronged strategies towards their protection and management is being employed for *in situ* conservation of enormous biodiversity including of FGR they harbour.

16.9.5

Creation of FGR Database

In addition to the above described four Components, their sub-components and specific tasks, the Pilot Project also envisaged the creation of FGR database incorporating varied baseline information generated through the present efforts on different aspects of conservation of FGR. The project has been successful in accomplishing this important task specific to Uttarakhand, as a pioneer effort, ultimately giving the shape for the development of FGR database in the context of country (IND-FGR) by incorporating similar information on FGR species from other States/ UTs in time to come. The present efforts towards the development of UK-FGR database would certainly provide the direction to other States and serve as comprehensive platform for wider dissemination of much desired information on FGR. The structure of UK-FGR database includes four Project Components as Modules (FGR-DOC, FGR-SGS, FGR-CHR, and FGR-COS) and respective sub-components as sub-modules besides specific activities. The UK-FGR is also linked to digitized DD Herbarium. Like any other advanced web portal-based database, UK-FGR is simple and user friendly, and offers a wide range of opportunities for different clients - policy and decision makers, field practitioners, scientists, etc. by way of species-specific query and report generation. Presently, the newly created State specific database is in testing and validation phase, and as much as possible information generated through the Pilot Project is being incorporated to make it more effective and efficient. This database is expected to play a vital role in facilitating the varied functions of the CoE-FGR.

6.10

Comprehensive and Comparative Insight on Five Prioritized FGR Species

The concurrent multidisciplinary and multiscale studies carried out under four Components of the Pilot Project provided an opportunity to develop a comprehensive as well as comparative insight on five ecologically and socioeconomically important forest tree species selected for the purpose of characterization and has been summarized in Table 16.1. Accordingly, these five species occurred in 4 to 12 forest sub-types of Uttarakhand. *B. utilis* was recorded from just four forest sub-types, representing two Forest Type Groups, indicating highly restricted distribution (2,800-4,000 m) in the Great Himalayan Range. In contrast, two species *viz., Q. semecarpifolia* and *R. arboreum* were found to be distributed across as many as 12 different forest sub-types. Remaining two species (*M. esculenta* and *T. wallichiana*) were found in 11 different forest sub-types out of total 39 forest sub-types recorded in the State. Thus, except *B. utilis*, four characterized species had relatively wider distribution in terms of their occurrence across varied forest sub-types. As a result, *B. utilis* was recorded from three Forest Divisions (FDs) and one PA, while *R. arboreum* occurred in as many as 14 FDs and 1 PA i.e., 15 divisions out of 39 (FDs and Wildlife Divisions). Three characterized species *viz., B. utilis, Q. semecarpifolia*, and *R. arboreum* are species of sub-alpine forests, while *M. esculenta* and *T. wallichiana* occurred in temperate forests.

Five species selected for characterization showed estimated range of ecogeographic distribution varying from 305.16 km^2 (*B. utilis*) to 832.40 km^2 (*Q. semecarpifolia*). In general, all five species registered relatively higher extent of potential ecogeographic distribution range based on MaxEnt Modeling than other prioritized FGR species (Table 16.1). Amongst three forest canopy/ cover classes, the maximum extent of ecogeographic distribution in case of all five species was registered in MDF. B. utilis exhibited the lowest extent in VDF as this species rarely shows gregarious distribution and occurs sparsely. Amongst five species, notably *B. utilis* showed maximum distribution extent in terms of potential area and percent representation in PAs, while in contrast, *M. esculenta* registered minimum distribution range and extent representation in PAs. All five species exhibited overall 'Good' regeneration.

Amongst five species, superior populations identified based on biochemical characterization (TTCs, TPCs, TFCs, and 10 DAB III) were predominantly confined in the higher altitude areas of Pithoragarh district (e.g., Himkhola, Dharchula, Darma) and higher elevation areas in Uttarkashi district (Har ki Dun, Harshil). Based on molecular characterization, *M. esculenta* widely distributed across 11 forest sub-types exhibited the highest genetic diversity (highest expected heterozygosity and allelic richness) amongst sampled populations besides showing the maximum level of gene flow. In contrast, *Q. semecarpifolia* exhibited the lowest level of gene flow owing to the presence of genetic barriers among the sampled populations, and thus revealing two distinct gene pools (GHC and MHC gene pools) with high genetic differentiation among them. Sampled populations of *B. utilis* exhibited maximum number of unique alleles (Table 16.1). The pathological characterization of five species revealed the highest proportion of healthy populations in case of *M. esculenta*, followed by *B. utilis*.

16.10.1

Relationship Among Three Types of Characterization

Using plant material from same sampled populations, characterization based on three different sciences *viz.*, biochemistry, genetics, and pathology offered valuable insight on chemically superior, genetically diverse, and healthy populations, respectively of five targeted species. Efforts were made to establish relationship among findings arising from three types of characterization.

16.10.1.1

Biochemical vs Molecular Characterization

Altogether, 17 out of 61 studied populations of five targeted species were identified as biochemically superior. Twenty-eight populations out of 106 sampled populations in case of five species were found genetically diverse (Table 16.1). Eight biochemically superior populations *viz.*, BU06, BU11, ME15, ME16, QS09, QS19, RA11, and TW19 were also identified as the genetically diverse populations, representing 47.05 per cent affinity among two types of characterization. Thus, these two types of characterization showed reasonably high positive relationship.

16.10.1.2

Biochemical vs Pathological Characterization

Efforts were made to check for any positive relationship between biochemically superior and healthy populations. The Pilot Project determined biochemically superior populations based on higher quantities of plant secondary metabolites (PSMs) *viz.*, phenolics, flavonoids, terpenes, etc. (quantified as TTCs, TPCs, TFCs, 10 DAB III) produced by them when they are under stress and varied PSMs play pivotal role as a strategy towards the defense mechanism. Obviously, plants with higher quantities of PSMs provide them an extra edge to fight against the pathogenic infestation as they help in providing 'induced resistance' and facilitate growth. In view of this, three most superior populations identified in each of the five targeted species based on their biochemical characterization were taken into consideration to confirm their affinity with the segregated healthy populations based on pathological characterization. Interestingly, out of 15 biochemically superior populations, seven populations *viz.*, BU06, BU09, ME15, ME16, QS08, RA03, and TW10 showed positive relationship between the two types of characterization (biochemical and pathological) (Table 16.1).

16.10.1.3

Pathological vs Molecular Characterization

The pathological characterization of five species revealed the highest proportion of healthy populations in case of *M. esculenta*, followed by *B. utilis* which can be corroborated with the high level of genetic diversity documented in these species in terms of allelic richness and presence of unique alleles, respectively. Evident higher genetic variability in the two species might be responsible for imparting higher adaptive potential to these species, enabling them to resist against pathogenic infestations. The recorded lower percentage of healthy populations (or in other words highest percentage of unhealthy populations) in case of *Q. semecarpifolia* and *T. wallichiana* could be substantiated with the relatively lower genetic diversity exhibited by these species in terms of allelic richness and presence of unique alleles. Above section has successfully attempted to establish positive relationship between genetic diversity (molecular characterization) and healthy populations (pathological characterization), specifically identified based on disease incidences.

Above stated startling revelations and positive affinities established among three types of characterization amply justify the importance of characterization process carried out towards conservation of FGR species by availing optimal advantage of concurrent multidiscipline and multiscale studies. Three populations *viz.*, BU06 (Himkhola), ME15 (Takula), and ME16 (Shitla Khet) were found to be superior in terms of their biochemical contents, genetic diversity, as well as resistant to pathogens. These three populations deserve highest conservation priority. In addition, there are several other populations those are superior at least on the basis of two different types of characterization.

16.11

Experiences and Future Prospects

The Pilot Project as a part of the wider 20-year prospective 'National Program for Conservation of FGR' offered a variety of learning experiences and provided pathways for dealing with similar future efforts in other States of the country. The project was first of its own kind in the long standing of FRI or even in the context of Indian forestry wherein a comprehensive multidiscipline, multiscale, multitechnique, and multistakeholder approach was adopted on FGR in the vast Himalayan State of Uttarakhand. Prior to this, varied scientific Divisions within FRI mostly worked in silos and there were little efforts in past towards integration of holistic insight developed through multidiscipline. Obviously, initially there were issues related to coordination across Divisions and their relevant scientific teams, and organization of field explorations, surveys, and assessments in a difficult State on account of inaccessible areas, rugged terrain, and harsh climatic conditions besides bringing the desired level of consistency in large datasets generated by multiteam working concurrently. In addition to these initial glitches, project activities hampered considerably due to covid-19 pandemic and resultant lockdown. The extension of project tenure by one and a half years, and regular interaction with participating team members and progress review immensely helped in overcoming varied constraints, limitations, and issues of coordination and consistency. In the end, efforts have been made to synthesize information and integration of understanding developed across different disciplines immensely helped in providing an insight on 'what was achieved' and 'what needs to be done' using the generated baseline information and knowledge. Some of the important learnings and emerging newer requirements are highlighted below:

Knowledge of the Species and Value of a Systematic Approach: The project has successfully made a beginning to explore the diversity of FGR species, and generation of wider field knowledge through documentation of information on their distribution, population structure, regeneration status, seed biology and storage behaviour, propagation techniques, characterization specific to biochemical, molecular, and pathological attributes, and conservation strategies. Present contribution is minuscule, considering the overall plant diversity including FGR species. This vital information remains unknown or poorly understood for majority of the FGR species. This situation demands resolute support for attending lesser-known species as well as threatened species on a priority and generation of much desired information on them. Waiting for elusive research information generated through protracted and cumbersome process may not be helpful in view of the unprecedented loss of forest biodiversity at a faster pace. Instead, a concurrent systematic approach to conservation based on robust principles also needs to be considered. A systematic approach requires an initial phase where priorities are discussed based on the known and anticipated threats on the FGR including climate change. It would be worth to consider the 'Forest Tree Genetic Risk Assessment System', a tool for conservation decision making in changing times and apply for robust, objective and evidence-based criteria for prioritization of FGR species. It also involves evaluating the different existing options to develop an effective conservation and use strategy. Potential conservation populations will have to be identified, surveyed, and conservation efforts implemented in a systematic approach in the field. Such an approach may need some adjustments in institutional structures and even necessary involvement of local people to facilitate effective conservation. The National Program on FGR has already envisaged concurrent research on across different States/ UTs involving nine leading forestry research institutes under the umbrella of ICFRE besides development of FGR database and CoE-FGR. Surely, these ongoing activities would provide desired momentum and strengthen efforts for conservation of FGR.

Sr. No.	Component/ Species	*Betula utilis* D. Don	*Myrica esculenta* Buch. -Ham. ex D. Don
A.	**FGR Documentation**		
A.1	**Species Profile-Distribution, Population Structure and Regeneration Status**		
A.1.1	Family	Betulaceae	Myricaceae
A.1.2	Local/ Common Name	Bhojpatra, Bhuj	Kaiphal, Kaphal
A.1.3	Synonyms	Betula bhojpattra var. latifolia Regel+C9:G15	*Myrica nagi* sensu Hook.f.; *Myrica esculenta* (Buch. -Ham. ex D. Don) I.M. Turner
A.1.4	Threats	Anthropological pressure (Ecotourism & Climate change)	Anthropological pressure (Over extraction of fruit)
A.1.5	Uses	Bark is papery ancient manuscripts were written on the sheets of this bark.	Fruits eaten raw and make refreshing squash
A.1.6	Distribution	It is a timber line species, and gregarious in higher elevations with *R. anthropogon* as an under shrub. Occurs along the Great Himalayan Range between 2,800 m and 4,000 m	It is a species of sub-temperate region within Lesser Himalayas and occurs from 1,400 m to 2500 m.
A.1.7	Occurrence in Forest Types	14/C1b, 14/C1a, 14/1S1, 15/C1	9/C1a, 9/C1b, 9/C1/DS1, 9/C1/DS2, 12/C1a, 12/C1b, 12/C1c, 12/C1d, 12/1SI, 12/C1f, 12/C2b
A.1.8	Forest Divisions	Pithoragarh, Uttarkashi, Bageshwar and Valley of Flowers NP	Nainital, Chakrata, Uttarkashi, Bageshwar, Tons, Pithoragarh, Kedarnath, Rudraprayag, Mussoorie, and Champawat
A.1.9	Population Structure and Regeneration Status	Species recorded overall 'Good' regeneration in sampled forest sites.	Species exhibited 'Good' regeneration. However, population was scanty.
A.2	**Ecogeographic Distribution**		
A.2.1	Climatic Status	Sub-alpine	Temperate
A.2.2	Estimated Area (km^2)	305.16	477.26
A.2.3	VDF (km^2)	11.75	111.17
A.2.4	MDF (km^2)	241.14	260.52
A.2.5	OF (km^2)	52.27	105.57
A.2.6	Representation of GA (%)	0.57	0.89
A.2.7	Representation of FC (%)	1.26	1.90
A.2.8	Estimated Extent in PAs (km^2)	283.59	3.58
A.2.9	Representation in PAs (%)	92.93	0.75
A.2.9	Maximum Occurrence Districts	Uttarkashi, Pithoragarh	Almora, Pauri, Nainital
B.	**FGR Seed and Germplasm Storage**		
B.1	**Medium- and Long-Term Storage of Seeds**		
B.1.1	Weight of 1,000 Seeds (g)	NA	97.64
B.1.2	No. of Seeds/ g	NA	10
B.1.3	Initial Moisture Content (%)		>15, <25
B.1.4	Moisture Content (%) After Dessication or Seed Storge	NA	7
B.1.5	Method of Drying	NA	Silica Gel

	***Quercus semecarpifolia* Sm.**	***Rhododendron arboreum* Sm.**	***Taxus wallichiana* Zucc.**
	Fagaceae	Ericaceae	Taxaceae
	Kharsu	Burans	Thuner, Thuniara
	Quercus obtusifolia D. Don.	*Rhododendron windsorii* Nutt.	*Taxus baccata* L.subsp. *wallichiana* (Zucc.) Pilg.
	Anthropological pressure (Developmental activities)	Over exploitation of flower for juice and wood for charcoal.	Anthropological pressure (Developmental activities)
	Timber, fodder, acorn favoured by bears.	Juice, fuelwood, quality charcoal.	Bark substitute of tea, medicinal.
	It is a gregarious species forming pure stands. It is a pioneer and climax species distributed from upper temperate to sub-alpine regions (2,100-3,500 m).	It is a widely distributed species in the Himalayas in the altitudinal range of 1,800-3,000 m, and occurs in forests of Garhwal and Kumaon regions. It is the State Tree of Uttarakhand.	Species has a wide distribution in the temperate Himalayan region in the altitudinal range of 1,800-3,400 m. It is common in the Greater Himalayan Range but scarce in Middle and Outer Himalayas
	12/C1b, 12/C1c, 12/C1d, 12/C1f, 12/C1e, 12/C2a, 12/C2b, 12/C2c, 12/C1/DS2, 13/1S1, 14/C1b, and 14/1S2	9/C1a, 9/C1b, 9/C1/DS1,12/C1a, 12/C1b, 12/C2b, 12/C1c, 12/C2c, 12/C1d, 12/C1e, 12/C1f, and 14/C1b	9/C1b, 9/C1/DS2, 12/C2b, 12/C2c, 12/C1b, 12/C1d, 13/1S1, 14/C1b, 14/1S2, 15/C1, and 16/E1
	Nainital, Kedarnath, Uttarkashi, Rudraprayag, Champawat, Upper Yamuna, Chamoli, Bageshwar, Badrinath, Chakrata, and Pithoragarh	Champawat, Uttarkashi, Bageshwar, Nainital, Pithoragarh, Kedarnath WLS, Rudraprayag, Mussoorie, Upper Yamuna, Tehri, Tons, Narendranagar, Badrinath, Almora, and Lansdowne	Pithoragarh, Uttarkashi, Bageshwar, Rudraprayag, Kedarnath, Upper Yamuna, Narendranagar, Badrinath, and Chakrata
	Species exhibited overall 'Good' regeneration. Higher number of adult tree individuals from lower diameter classes indicating species was evolving.	Species exhibited overall 'Good' regeneration in its natural range.	Species depicted overall 'Good' regeneration in its natural range.
	Sub-alpine	Sub-alpine	Temperate
	832.40	617.48	545.86
	214.15	167.48	148.00
	512.47	320.75	336.58
	105.79	129.25	61.29
	1.56	1.15	1.02
	3.43	2.54	2.25
	183.04	92.00	151.04
	21.99	14.90	27.67
	Chamoli, Pithoragarh	Champawat and Pauri	Uttarkashi, Chamoli
	NA	0.011-0.013	NA
	NA	ca. 9,000	NA
		≤15	
	NA	7	NA
	NA	Silica Gel	NA

Sr. No.	Component/ Species	*Betula utilis* D. Don	*Myrica esculenta* Buch. -Ham. ex D. Don
C.	**FGR Characterization**		
C.1.	**Biochemical Characterization**		
C.1.1	Number of Sampled Populations	11	12
C.1.2	Range in Varied Contents with Minimum and Maximum Values Across Sampled Populations	Total Triterpenoid Contents (TTCs) in the stem bark ranged from 10.07-31.23 mg ursolic acid equivalent/g of bark	Values of Total Phenolic Contents (TPCs) in the bark ranged from 11.38-27.13 mg GAE/g of bark
C.1.3	Identified Superior Populations based on Biochemical Contents	Niti (BU03), Himkhola, Dharchula (BU06), Har ki Dun(BU09), and Darma Valley (Bu11) based on TTCs	Kausani (ME14), Takula (ME15), and Shitla Khet (ME16) based on TPCs
C.2	**Molecular Characterization**		
C.2.1	Number of Sampled Populations	11	23
C.2.1	Expected Heterozygosity (*He*)	Range - (0.734-0.828); Mean - 0.785	Range - (0.834-0.897); Mean - 0.866
C.2.2	Allelic Richness (Rs)	Range - 7.58- 10.79; Mean - 9.403	Range - 10.84- 15.06; Mean - 13.446
C.2.3	Private Allelic Richness (PRs)	Range - 0.46- 2.23; Mean - 1.216	Range - 0.22- 1.70; Mean - 0.587
C.2.4	Gene Flow (*N*m)	2.968	6.137
C.2.5	Genetic Differentiation (F_{ST})	0.081	0.038
C.2.6	Population Structure	Four Genepools Gene pool-I (BU03-BU05), Gene pool-II (Bu10), Gene pool-III (BU02, Bu09), Genepool-IV (BU01, BU11)	Three Gene pools with high level of admixed ancestry
C.2.7	Genetic Diversity Hotspots	BU01, BU06 , BU10 , and BU11	ME08 , ME15 , ME16 , ME17 , and Me18
C.3	**Pathological Characterization**		
C.3.1	Sampled Populations (Number)	11	23
C.3.2	Healthy Populations (Number, Names/ Codes, and Percentage of Healthy Populations)	Five Populations: Bamni village, NDBR (Bu04), Himkhola (Bu06), Hemkund Sahib (Bu07), Har ki Dun (BU09), and Darma Valley (Bu11); 45.45%	Twelve Populations: Gairsain (ME02), Karnaprayag (ME04), Chirapani (Me05), Kamlekh (ME07), Ranikhet (Me12), Dunagiri (ME13), Takula (Me15), Shitla Khet (ME16), Mayali (Me18), Lansdowne (ME20), Gwaldam (Me21), and Mornaula (ME23); 52.17%
C.3.3	Occurrence of Fungal Species (Number of Species)	10	10
C.3.4	New Fungal Records (Number of Species)	8	10
D.	**FGR Conservation**		
D.1	**Standardization of Propagation Techniques**		
D.1.1	Recommended Methods of Propagation and Success Rate (Plant per cent)	NA	Branch cuttings: 10 to 13 per cent survival; Seeds: 26 to 36 per cent survival

	Quercus semecarpifolia Sm.	*Rhododendron arboreum* Sm.	*Taxus wallichiana* Zucc.
	14	9	15
	Values of Total Phenolic Contents (TPCs) in the leaves ranged from 5.66-33.77 mg GAE/g of leaves	Values of Total Flavonoid Contents (TFCs) in flowers ranged from 1.75-56.57 mg QE/g of flowers	Values of Contents of 10-Deactylbaccatin III in needles ranged from 1.33-6.19 mg/g of needles
	Yamunotri (QS08), Radi Top (QS09), and Mundhola (QS19) based on TPCs	Janglatchowki (RA03), Budher (RA04) and Chaurangikhal (Ra11) based on TFCs	Deoban (TW02), Harshil (TW06), Ghes (TW10), and Har ki Dun (TW19) based on 10 DAB III
	24	27	21
	Range - (0.629-0.814); Mean - 0.721 Mean - 0.707	Range - (0.753-0.878);	Range - (0.623-0.804); Mean - 0.725
	Range - 6.71- 9.77; Mean - 8.373	Range - 7.89- 12.69; Mean - 10.864	Range - 6.29- 9.41; Mean - 7.501
	Range - 0.05- 0.69; Mean - 0.321	Range - 0.01- 1.61; Mean - 0.442	Range - 0.00- 0.92; Mean - 0.312
	2.236	3.132	3.6
	0.156	0.064	0.068
	Two distinct Gene pools GHC gene pool- (QS02-QS08), and MHC gene pool- (QS01, QS09-QS24)	Two Gene pools Gene pool-I (RA01-RA07), Gene pool-II (RA08-RA27)	Two Gene pools with high level of admixed ancestry
	QS09 , QS11 , QS15 , QS19, QS21 , QS23 , and Qs24	RA11 , RA16 , RA18 , RA19 , RA22 , RA23 , and RA24	TW12 , TW15 , TW18 , TW19 , and Tw21
	24	27	21
	Ten Populations: Deoban (QS03), Auli (QS07), Yamunotri (Qs08), Bhukkitop (QS11), Naina Peak (Qs13), Badhanital Forest (QS14), Ghes (Qs17), Balcha (QS18), Nag Tibba (QS20), and Narayan Ashram (QS23); 41.66%	Twelve Populations: Janglatchowki (Ra03), Gairsain (RA06), Siutal (RA08), Sandev (Ra09), Dudhatoli (Ra12), Peethsen (Ra13), Adwani (RA15), Chirbatiya (RA18), Badhanital (RA19), and Ghes (RA23); 44.44%	Nine Populations: Bhujkoti (TW03), Auli (TW05), Sukkhi Top (TW07), Ghes, (TW10), Mundhola (TW12), Ghangaria (TW16), Mornaula (TW18), Triyuginarayan (TW20), and Baling (TW21); 42.8%
	22	22	18
	22	21	14
	NA	Air layering: 38 to 60 per cent survival; Seeds: 9 to 25 per cent survival; Root cuttings: 7 to 27 per cent survival	Branch cuttings: 70 to 77 per cent survival; Air layering: 35 to 40 per cent survival

Sr. No.	Component/ Species	*Betula utilis* D. Don	*Myrica esculenta* Buch. -Ham. ex D. Don
D.2	**Establishment of *In Situ* Forest Gene Conservation Units (FGCUs)**		
D.2.1	Location of FGCUs	4 FGCUs: BU01 (Rudranath, Kedarnath WD), Bu06 (Himkhola, Pithoragarh FD), BU10 (Triyuginarayan, Rudraprayag FD), and BU11 (Darma Valley, Pithoragarh FD)	5 FGCUs: ME08 (Sandev, Pithoragarh FD), ME15 (Takula, Almora FD), Me16 (Shitla Khet, Almora FD), Me17 (Bhowali, Nainital FD), and Me18 (Mayali, Rudraprayag FD)
D.3	**Establishment of *Ex Situ* Field Gene Banks (FGBs)**		
D.3.1	Seed/ Germplasm Source	NA	Three: Askot, Devidhura, Khirsu
D.3.2	Location of FGB	NA	Compartment No. 23, Bhowali Forest Range, Nainital FD
D.3.3	Geo Coordinates of FGB	NA	N 29°23'25.1"E 79°27'40.7" Alt- 1,564 m

Strengthening Systematic Forest Botany and Adequacy of Field Sampling: The Pilot Project in the context of Uttarakhand was in an advantageous situation as it could avail optimum benefit of experienced and well-known forest botanists, taxonomists, DD Herbarium, arboretum, the National Forest Library, and Forest/ Wildlife Plans. The role of forest botany, taxonomy and experts having field information on distribution, threats, and uses of FGR cannot be undermined while considering any action towards their conservation. There is an urgency to appreciate that this valuable science (forest botany, taxonomy) is on decline, it needs strengthening and to promote the concept of para taxonomists for wider coverage and to facilitate adequate field level assessments, especially on abundance and distribution. The project enabled digitization of nearly one-third specimens of the DD Herbarium. Continued efforts and support are needed to complete the task of digitization of remaining two-third specimens. Presently, the herbarium has distributed specimens across broad ten geographic regions spelt out during the British regime, much prior to the independence of the country. There is a felt need to appropriately incorporate names of State/ UTs in digitized database so distribution of plant specimens collected from the territory of independent India could be digitally segregated at ease. Stratification and adequate field sampling are must, specifically in the case of assessments on population structure and regeneration status. Future efforts on documentation need to carefully look into aspects of appropriate stratification and adequate sampling so as to generate precise information on distribution and regeneration status in different forest sub-types.

Development of Guidelines and Protocols: In the process of execution of Pilot Project, different scientific Divisions and multidisciplinary teams developed protocols relevant to field methods, laboratory investigations, and procedures for integrating them. There is a felt need to document these protocols and relevant guidelines for wider use among nine ICFRE institutions involved in similar efforts on FGR in other States to ensure uniformity in datasets to be ultimately incorporated in the National Database on FGR.

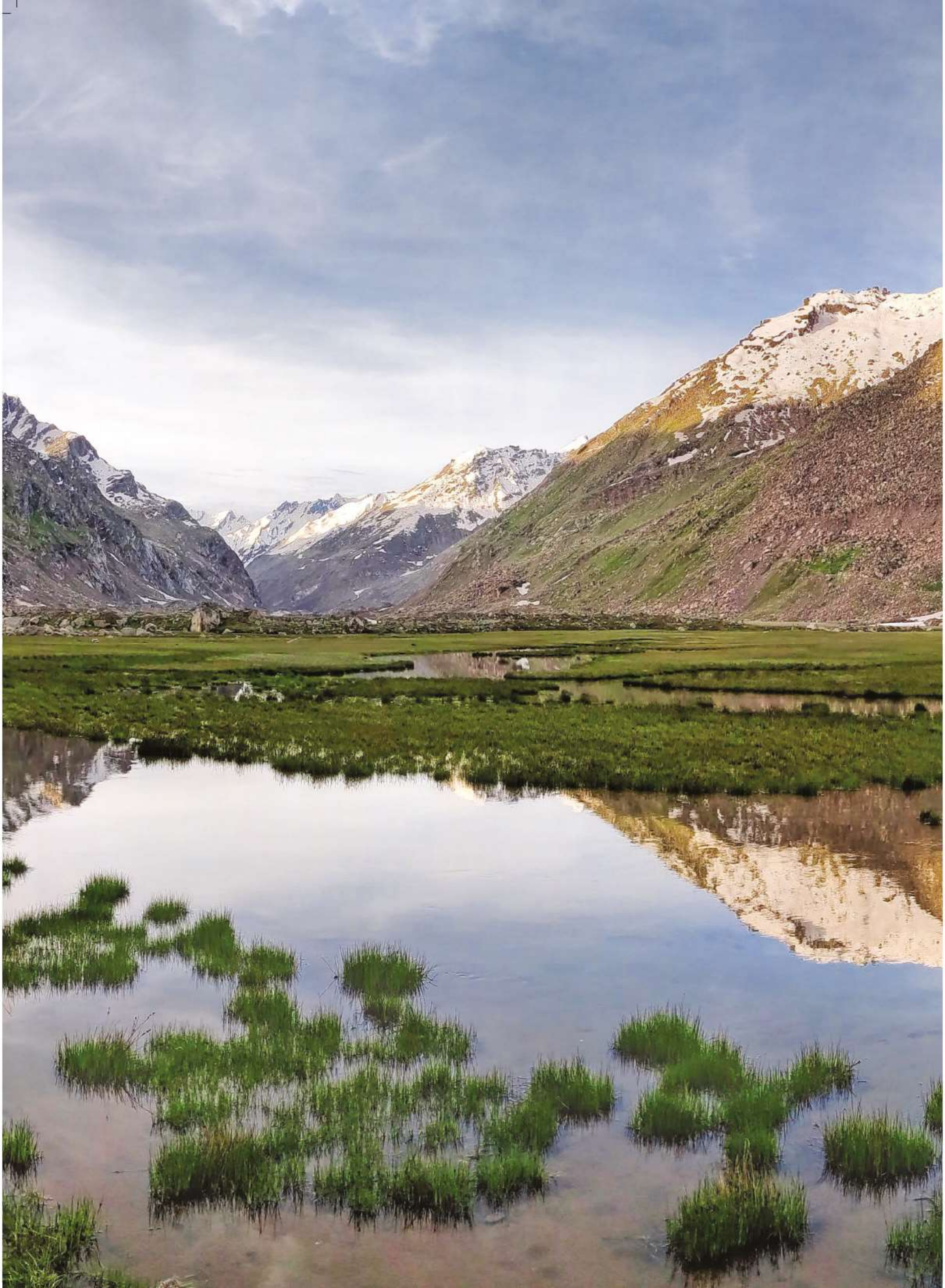
Collaboration and Partnership: Contributions towards the Pilot Project were predominantly made by the varied scientific teams of FRI. The State Forest Department through Working Plans and Management Plans generate enormous information on forest species especially on the distribution, uses, and regeneration status. There is an urgent need to optimally utilize such information generated by SFDs to strengthen and augment current efforts towards FGR conservation and develop State specific databases. Active involvement and partnership of SFDs and other stakeholders in improving the availability of, and access to information on FGR, and their documentation and conservation is of utmost importance and cannot be overemphasized. In addition, collaboration and networking with other national and international organizations would also be desirable to establish linkages with other databases and mutual sharing.

Integrated Approach and *In Situ* Conservation of Multiple Species: Most plant species growing in forests around the world depend on conservation in situ as they are not currently planted, and the majority probably never will be, at least in the foreseeable future. The foregoing section has attempted to highlight relationship among different types of characterization. Neither it is feasible nor desirable to establish population specific gene conservation units in case of individual species considering vast diversity of FGR. Thus, efforts need to be made to identify genetic diversity hotspots for multiple species at a given field site as in the present case some specific sites/ FDs have emerged as the concentration zones harbouring genetic diversity hot spots of multiple species. Moreover, there is a need to identify superior populations in each case based on comprehensive characterization involving biochemical, molecular, and pathological aspects in lieu of isolated efforts.

	Quercus semecarpifolia Sm.	*Rhododendron arboreum* Sm.	*Taxus wallichiana* Zucc.
	7 FGCUs: QS09 (Radi Top, Upper Yamuna Barkot FD), QS11 (Bhukkitop, Uttarkashi FD), QS15 (Munsiyari, Pithoragarh FD), Qs19 (Mundhola, Chakrata FD), QS21 (Pinswar, Rudraprayag FD), QS23 (Narayan Ashram, Pithoragarh FD), and QS24 (Himkhola, Pithoragarh FD)	7 FGCUs: RA11 (Chaurangi Khal, Uttarkashi FD), Ra16 (Dunagiri, Almora FD), Ra18 (Chirbatiya, Tehri FD), Ra19 (Badhanital, Rudraprayag FD), RA22 (Dhanaulti, Narendranagar FD), RA23 (Ghes, Badrinath FD), and RA24 (Gwaldam, Badrinath FD)	5 FGCUs: TW12 (Mundhola, Chakrata FD), TW15 (Himkhola, Pithoragarh FD), TW18 (Mornaula, Nainital FD), TW19 (Har ki Dun, Govind WLS and NP), and TW21 (Baling, Pithoragarh FD)
	NA	Four: Pauri, Tehri, Uttarkashi, Chakrata	Four: Chakrata, Ghangariya, Dayara Bugyal, Joshimath
	NA	Compartment No.04, Thali, Devidhura Forest Range, Champawat FD	Malari Beat, Suraithota Section, Joshimath Forest Range, Nandadevi NP
	NA	N 29°26'50.3" E 79°46'57.0" Alt- 2,161 m	N 30°42'2.161" E 79°52'0.367" Alt- 3,514 m

Complementarity of Conservation Methods: Existing approaches primarily focus on the conservation of genetic resources in their natural habitats. *In situ* conservation is only a technical option in a broader approach to conservation of the diversity between and within species. Moreover, conserving forest trees in situ may be the only method that is ecologically, socially, and economically possible. Hence, a combination of approaches including Protected Areas, Managed Forests, *circa situm* repositories, agro-wood lots, clone banks, plantations and breeding programs may be better suited in a framework of landscape approach to conservation and multiple objectives of forestry. The landscape approach to conservation would facilitate dynamic multispecies conservation besides ecological and evolutionary processes.

Long Term Monitoring: The Pilot Project has generated enormous valuable baseline information relevant to field level parameters as well as analytical attributes based on multifarious laboratory investigations. Since similar efforts are being made in other States as a part of the National Program, voluminous information on varied aspects of FGR is likely to be generated which need to be incorporated and integrated in the national level FGR database. However, there is an urgent need to plan for periodic monitoring of prioritized FGR species for comparison with the baseline information generated through the Pilot project. Such monitoring effort would timely provide an insight on changes in FGR, especially on account of developmental activities and climate change.



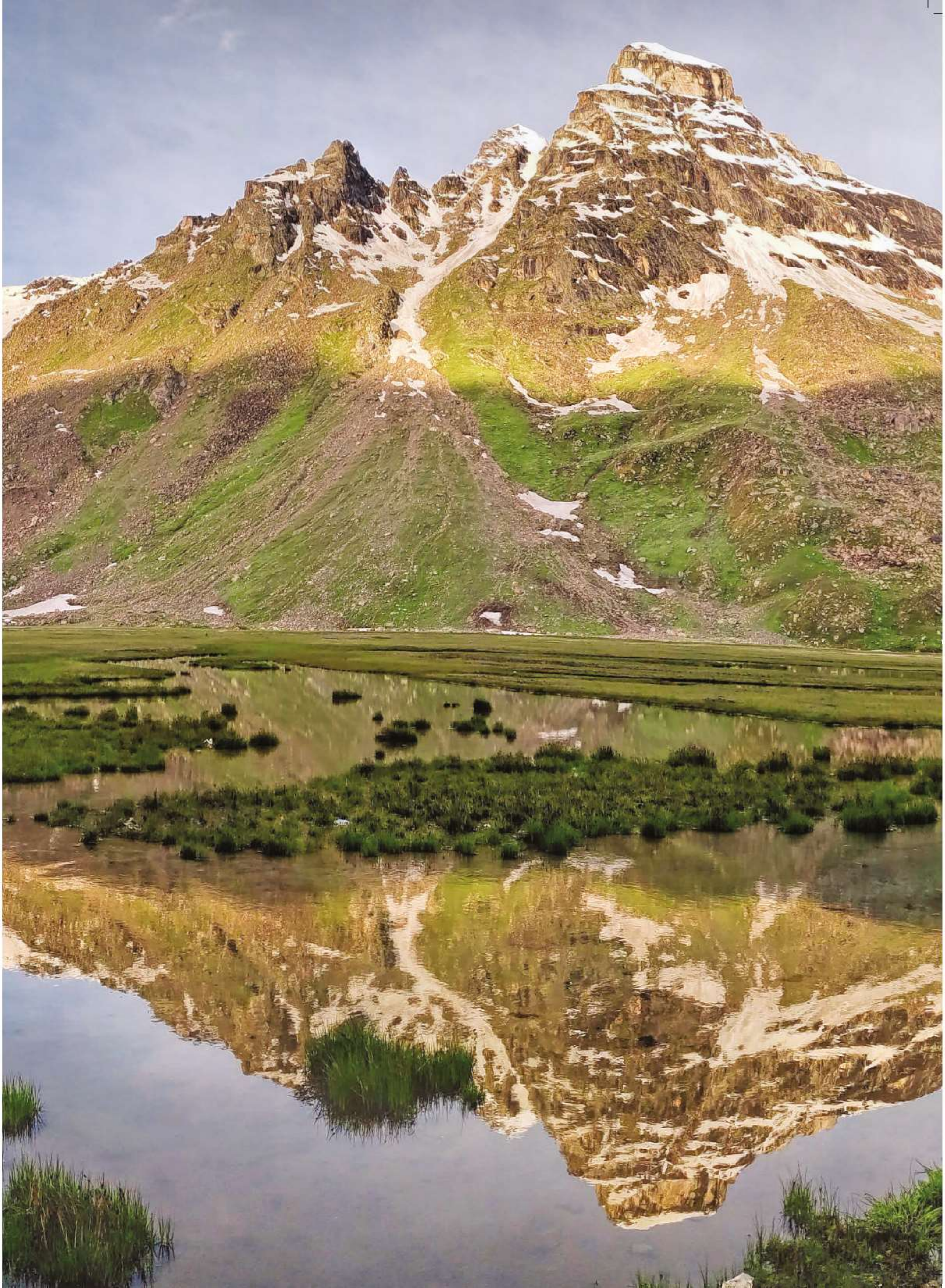


PHOTO CREDIT

Sr. No.	Name of Photographer	Description
1.	Sh. Bhumesh Bharti	Woody Climber Twinning a Tree - 21 Page; Forest During Sunrise Near Rishikesh - 43 Page; Habitat of Rhododendron rawatii - 46 Page; Mixed Forest Near Mussoorie - 49 Page; Rhododendron Forest at Chopta - 82 Page, 811 Page; Forests and Himalayas - 118 Page; Forests and People - 120 Page, 135 Page, 136 Page; Agriculture Landscape in Uttarakhand - 134 Page; Roadside Forest - 418-419 Page; Forest Trail at Mussoorie - 420 Page; Prunus and Banderpunchh Peak, Lakhamandal - 517 Page; Fruit of Myrica esculenta (Kafal) - 651 Page.
2.	Ms. Haripriya Kavidayal	Botanical Garden FRI - 25 Page; Mesmerizing View of Forest - 94 Page.
3.	Sh. Harsh Rawat	Tiger - 130 Page; Passage Through Forest - 171 Page;
4.	Sh. Manish Kabdwal	Landscape of Forest and Himalayas - 126 Page; Forest and Mountain View in Satoli, Mukteshwar - 132 Page; Rhododendron arboreum-State Tree of Uttarakhand - 456 Page; Expedition in the Himalayas - 776 Page; River Across Mountains - 798 Page; Scenic View on the Way to Satoli - 814 Page; Trans Himalayan Landscape - 838-839 Page.
5.	Sh. Rajneesh	Habitat of Rhododendron at Khaliya Top, Munsiyari - 51 Page; Dense Forest in Pithoragarh - 54 Page; Connectivity Between Forests and Glaciers in Baluni Bugyal - 106-107 Page; Forest Habitat in Niti - 144
6.	Sh. Sanjay Goyal	Fauna as an Integral Part of Forest Ecosystem - 100 Page; Life in Mountains - 114 Page; Pine tree - 128 Page, 169 Page; Pine Forest in Kumaon - 392 Page
7.	Sh. Threesh Kapoor	Life in mountains - 12-13 Page; Terrace Farming in Uttarakhand - 22 Page; River View Across Dense Deodar Forest - 529 Page; Dense Deodar Forest - 802 Page

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