Annual Progress Report (2018)

Title of the Project

''Vulnerability to disturbances, resource mapping and *ex-situ* conservation of endemic and relict species *Betula utilis* D. Don (Himalayan birch) in Sindh Forest Division of Kashmir''

Submitted by

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INTGRATED ECODEVELOPMENT RESEARCH PROGRAMME (IERP) IN HIMALAYAN REGION

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Uttaranchal

1. Title of the project: ‘‘Vulnerability to disturbances, resource mapping and *ex-situ* conservation of endemic and relict species *Betula utilis* D. Don (Himalayan birch) in Sindh Forest Division of Kashmir.’’

2. Name of Principal Investigator: Dr. P. A. Sofi

3. GBPIHED project sanction letter no and date of sanction:

GBPI/IERP-NMHS/15-16/20/09 dated 31.03.2016

4. Total outlay sanctioned: Rs. 12, 81,500.00 **4.1. Duration**: Three Years (3years)

5. Date of Start: 11.05.2016

6. Grant received during the year: Rs. 3,36,200.00

7. Expenditure incurred during the year: Rs. 2,61,782.00

8. Bound area of research: Study of ecological status and conservation of *Betula utilis*

9. Sub area of the project: a). Resource mapping of *Betula utilis* in Sind Forest Division

b). Production of quality plant material for ex-situ Conservation

10. Approved objectives of the project:

1. To Study tree line structure and diversity of *Betula utilis* dominated stands and document it through resource mapping along an altitudinal gradient in Sindh Forest Division.
2. To evaluate the regeneration behavior of *Betula utilis.*
3. To study phenology and morphological events of *Betula utilis* along an altitudinal gradient.
4. To determine the best treatment for propagating *Betula utilis* through seeds.

Introduction

The genus *Betula*, commonly known as birch, belongs to phylum Tracheophyta, class Magnoliopsida, order Fagales and the family Betulaceae. *Betula utilis* D. Don (Himalayan birch, Bhurja) a tree line species normally grows between an elevation of 2500 to 3600 m. Further upslope, the species grows scattered in a crippled growth form and merges with *Salix denticulate* belt which delimits timberline ecotone and thus the subalpine zone. In

its native habitat, *Betula utilis* tends to form forests, growing as a shrub or a moderate-sized tree reaching up to the height of 20 m (66 ft). At higher altitudes (> 3,000 m amsl) it is found in groves and closer groupings. In the Outer Himalayas it occurs in a mixed forest at all the exposures; frequently among scattered conifers, with an undergrowth of shrubs viz. *Rhododendron*. *Betula utilis* species is deciduous in nature with peeling white bark and ovate to oblong, tapered and glossy dark green leaves which turn yellow in autumn. Birches are monocious with small simple flowers situated in separate male and female catkins. Their light small pollen grains are produced in huge quantities and carried to long distances by the wind.

Betula utilis is a versatile plant with multifarious uses. The species is a unique source of phyto-chemical compounds-betulinic acid which shows many biological activities. Studies have revealed that betulinic acid inhibits growth of malignant melanoma and cancers of the liver and the lung (Anonymous, 1985; Thurnher *et al.,* 2003). *Betula utilis* yields an important compound known as betulin which is used as an important constituent of anti-inflammatory, antimicrobial, antioxidant antiviral and hepato protective drugs (Singh *et al.,* 2012). Essential oil of *Betula utilis* bark is antiseptic and carminative and is also reported to contain karachic acid which is aromatic with antiseptic properties (Sharma *et al.,* 2010). *Betula* bark can also be used to make a drink said to purify the blood. Birch leaves are used to make a diuretic tea for colds, dysentery and stomach ailments (Besendorfer and Kolevska, 1991). The leaves of the plant also show efficacy in treatment of urinary tract infections and in kidney and bladder stones (Tilford, 1997

Besides medicinal uses, *Betula* provides fodder for the livestock, bark peels for writing and timber for agricultural implements. The bark of Himalayan birch was used centuries ago in India as paper for writing lengthy scriptures and texts in Sanskrit. In the late 19th century, Kashmiri pandits reported all of their books were written on Himalayan birch bark until Akbar introduced paper in the 16th century (Muller *et al*., 1881). The most widespread use of birch is for firewood and timber (Singh *et al.,* 2012). The bark paper is used for packing ghee and making binding ropes and for wood protection from soil (Safdar *et al.,* 2017). The timber of birch is straight grained, strong and durable, making it useful for furniture and high quality plywood (Shaw *et al.,* 2014). The outer bark of birches has been traditionally used for packaging, water proofing, making wedding cards and roofing of mud houses. Plant also provides food, gums and resins(Safdar *et al*., 2017).

The massive deforestation and over-exploitation of *Betula utilis* trees for various purposes has caused loss/reduction of habitat in many of its native groves in the entire Himalayan range). Among the sixty three (63) near threatened (NT) species, the Himalayan birch in Kashmir has been assigned the status of critically endangered trees by ENVIS Centre on Conservation of Medicinal Plants, FRLHT, Bangalore. Contrary to this, IUCN/SSC Global Trees Specialist Group in its report has enlisted this species as data deficient. The ex situ conservation and massive plantation of this species in the natural zone of occurrence will thus be an important measure against the extinction of this taxa represented by very small wild populations. Although the community structure and regeneration of various *Betula* spp. has been extensively explored elsewhere in the world, the spatial patterns of vegetation composition and seedling recruitment of Himalayan birch (*Betula utilis*) in Kashmir is yet to invite the attention of researchers. The lack of information on community attributes of this tree line species and its ecology are the two major concerns to devise a management plan for restocking these high mountain forests (Stainton, 1972; Krauchi *et al.,* 2000). The ease and suitability of propagation methods for this species are also not well documented in the literature. With these shortcomings in mind the present project was undertaken in Sindh forest division of Kashmir.

11. Methodology

1. Study site

The present study was concentrated along the three altitudinal gradients of 3000 - 3200m, 3200 - 3400 and 3400-3600m amsl in two *Betula* stands at sindh forest division. The Sindh Forest Division lies between $74^{o}\,42^{/}$ to $75^{o}\,26^{/}$ East Longitude to $34^{o}\,7^{/}$ and $34^{o}\,28^{/}$ North Latitude. The entire area is covered by Survey of India G.T. Sheet Nos. 43N/3, N/4, N/7, N/8, N/12, J/11, J/12, J/15 and J/16. The total area of demarcated forests of Sindh Forest Division is around 37901 ha. The tract of the selected site in this Forest Division is extremely mountainous and full of ridges with rugged terrain. The whole Forest Division drains into Sindh river with many smaller nallahs from side valleys tributing to it . The altitude of this Forest Division ranges from 1587m amsl near Harran to 5248m amsl at Harmukh with study site is located between an altitude of 3000-3600m amsl.

2. Vegetation survey and analysis

A stratified random sampling method was employed and vegetation analysis on each altitude and aspect was replicated by laying quadrates on almost constant slope. This type of

analysis minimizes environmental influence other than those related to the altitude and aspect. The study area was divided into three altitudinal gradients of 3,000-3,200 m, 3,200-3,400 and 3400-3,600m amsl. Three (3) vertical transects running parallel to each other were laid at each study site and in each transect five (5) 10 × 10 m quadrates were demarcated at a definite interval along the available altitude and aspect. The trees were recorded in 10 × 10 m quadrant across the selected sites. The 10 × 10 m quadrates were further divided into two sub-quadrates of 5 × 5 m size (lying diagonally to each other) for recording shrubs. Further, the sub-quadrates were again divided in 1 × 1 m quadrates for recording ground flora. A Global Positioning System (GPS) was trailed to aid in location of quadrates along the altitudinal gradient at each site.

3. Community structure

3.1 Floristic composition

The vegetation survey conducted indicated that the selected sites of *Betula* dominated stands in Sindh forest division are rich in plant composition, supporting many plant species, of diverse taxonomic and ecological significance. *Betula* stands in Sindh forest division were prominent on South Eastern and South Western aspects in the altitudinal range of 3000 to 3600m. The total number of families supported by these stands was 26 (24 Angiosperms and 2 Gymnosperms) on South Eastern aspect and 28 (26 Angiosperms and 2 Gymnosperms) on South Western slopes.

The overall community structure of *Betula* stands at Sindh Forest Division depicted that while Asteraceae and Poaceae were the dominant families with 6 & 5 species on South Eastern aspect, the South Western aspect was dominated by Asteraceae and Rosaceae with 6 & 5 species respectively. Crassulaceae, Ericaceae, Lamiaceae, Poaceae, Polygonaceae, Ranunculaceae and Rosaceae, were other predominant families with representation of 3 species on South Eastern and South Western aspects. Pinaceae was represented by 3 and 2 species on South Eastern and South Western aspect. Further, while Balsaminaceae comprised 2 species on South Eastern aspect, Salicaceae and Violaceae were represented by 2 species on South Western aspect.

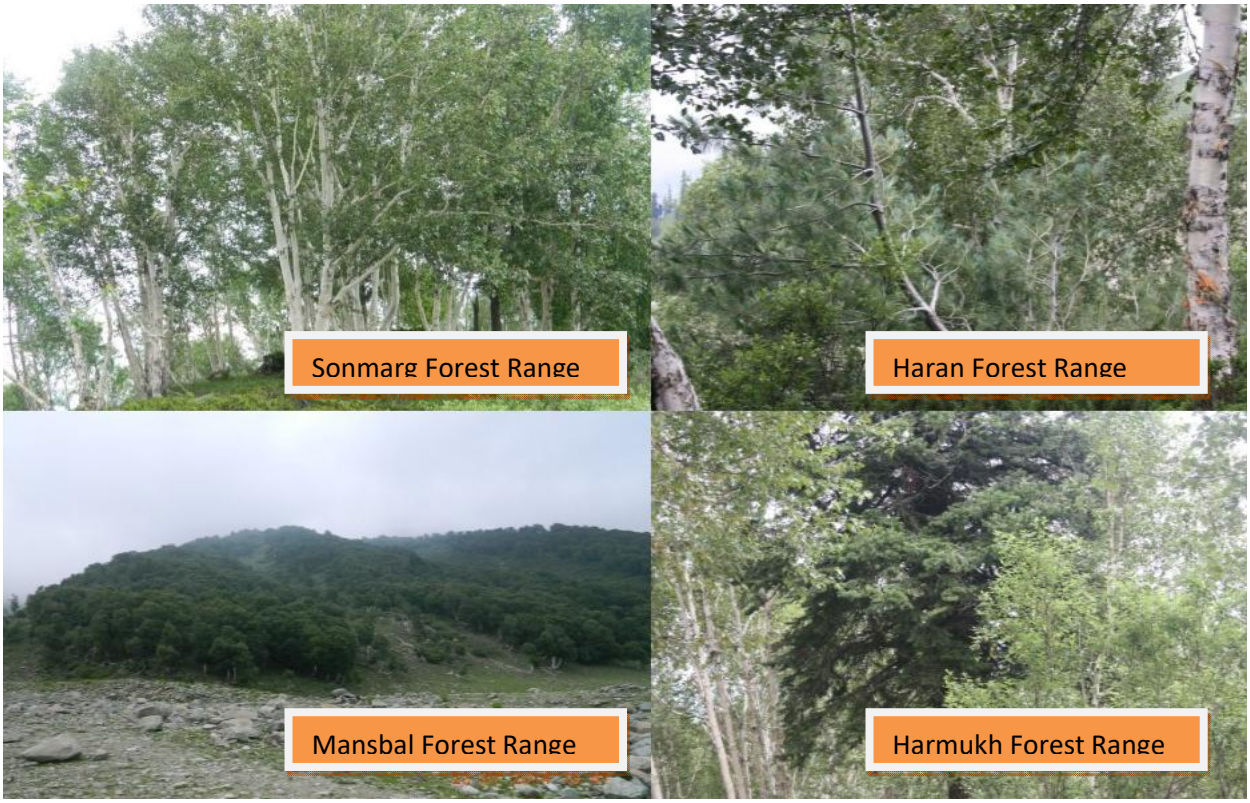


Fig.1 : *Betula utilis* stands stand at Sindh forest division

3. 2 Importance Value Index (IVI)

The data presented in Table 1 revealed that *Betula utilis* exhibited maximum and varied IVI on all the aspects along the three altitudinal gradients at Sindh forest division. The IVI of this species on South Eastern and South Western aspect was 156.92 and 181.85% at lower altitude (3000-3200m), 186.05 and 208.80% at middle altitude (3200-3400m) and 236.58 and 260.04% at the upper altitudinal range (3400-3600m). *Abies pindrow* exhibited IVI values of 65.97 and 66.95% on lower altitude and 61.79 and 39.97% on middle altitude along the South Eastern and South Western slopes. Further, while *Abies pindrow* exhibited IVI of 29.85% on South Eastern aspect, the species was exclusively absent on South Western aspect on the upper altitude. While, *Acer caesium* displayed IVI values of 54.54 and 28.24% on South Eastern and South Western aspects on lower altitude and 24.84 and 28.54% on the middle altitude. The species did not represent the upper altitudinal range of 3400-3600m. *Picea smithiana* with lone appearance at the altitude of 3000-3200m exhibited IVI values of 8.28% on the South Eastern aspect.

Table 1: Important Value Index (IVI) of tree species across the available aspects and altitudinal gradient in *Betula* dominant tree stands at Sindh forest division

Altitude (masl)	Species	Sindh Forest Division								
		South East				South West				
		RF	RD	RDo	IVI	RF	RD	RDo	IVI	IVI
3000-3200	*Betula utilis*	33.33	62.80	60.79	156.92	40.91	73.87	67.07	181.85	237.31
	Abies pindrow	25.93	19.40	20.64	65.97	27.27	15.65	24.02	66.95	42.57
	Pinus wallichiana	11.11	2.41	0.77	14.29	13.64	5.24	4.08	22.96	20.12
	Acer caesium	25.93	12.98	15.63	54.54	18.18	5.24	4.82	28.24	-
	Picea smithiana	3.70	2.41	2.17	8.28	-	-	-	-	-
3200-3400	*Betula utilis*	40.91	78.96	75.66	186.05	42.86	84.27	81.67	208.80	256.91
	Abies pindrow	36.36	13.53	11.90	61.79	23.81	7.87	8.29	39.97	19.93
	Pinus wallichiana	9.09	1.49	17.06	27.64	14.28	4.75	3.46	22.49	23.16
	Acer caesium	13.64	6.02	5.19	24.84	19.05	3.12	6.59	28.75	-
	Picea smithiana	-	-	-	-	-	-	-	-	-
3400-3600	*Betula utilis*	87.69	60.00	88.89	236.58	97.99	66.66	95.39	260.04	245.35
	Abies pindrow	5.40	20.00	4.44	29.85	-	-	-	-	35.79
	Pinus wallichiana	6.83	20.00	6.67	33.50	2.06	16.67	4.64	23.36	18.84
	Acer caesium	-	-	-	-	-	-	-	-	-
	Picea smithiana	-	-	-	-	-	-	-	-	-

3.3 Physiochemical properties of Soil in *Betula* dominant stands in Sindh Forest Division

3.3.1 Soil pH

Data summarized in Table 2 reveal that soil pH varied on both the aspects along the altitudinal gradient on each site. On South Eastern aspect at Sindh forest division the maximum soil pH (5.98) was recorded at lower altitude and minimum (5.26) at upper altitude. Similarly on South Western aspect the pH of soil was maximum (6.72) at lower altitude and minimum (6.01) at upper altitude.

3.3.2 Electrical conductivity (EC $dScm^{-1}$)

The appraisal of data (Table 2) depicts that electrical conductivity also varied along the altitude at both the sites. On South Eastern aspect at Sindh Forest Division the maximum electrical conductivity (0.37 $dScm^{-1}$) was recorded at lower altitude and minimum (0.24 $dScm^{-1}$) at upper altitudes. Similarly on South Western aspect the electrical conductivity was maximum (0.51 $dScm^{-1}$) at lower altitude and minimum (0.19 $dScm^{-1}$) at upper altitudes.

3.3.3 Bulk density (g cm^{-3})

The mean bulk density (g cm^{-3}) along the altitude varied significantly ($p \leq 0.05$) at both the locations (Table 2). On South Eastern aspect at Sindh Forest Division the maximum and minimum bulk density of 1.35 and 1.19 cm^{-3} was recorded at lower and upper altitudes respectively. Similarly on South Western aspect the maximum and minimum bulk density of 1.31 and 1.08 cm^{-3} was recorded on lower and upper altitudes respectively.

3.3.5 Soil texture classes under of *Betula* dominant stands in Sindh Forest Division

The data on Soil Texture classes in *Betula* dominant stands at Sindh Forest Division along the various altitudinal gradients and available aspects is summarized in Table 2. The soil texture on South Eastern aspect at Sindh Forest Division was clay loam at lower altitude (3000-3200m) with fractional components of 36.10, 34.20 and 29.70% for sand, silt and clay respectively. On middle altitudinal range of 3200-3400m the soil texture was loam with values 29.87, 45.45 and 24.68% for sand, silt and clay. The soil texture on South Eastern aspect at upper altitude was silt loam with sand (23.90%), silt (60.50%) and clay (15.60%). Similarly the soil texture on South Western aspect at lower altitude (3000m-3200m) was clay loam with percentage contribution of 35.30, 33.60 and 31.10% for sand silt and clay. On middle altitudinal range of 3200-3400m the soil texture was loam with sand (31.08%), silt (46.95%) and clay (21.97). The soil texture on South Western aspect at the upper altitudinal

range (3400-3600m) was silt loam with sand, silt and clay contents of 25.36, 61.62 and 13.02% respectively.

Table 2:Soil physical properties across the available aspects and altitudinal gradient in *Betula* dominant tree stands at Sindh Forest Division

Site	Altitude (amsl)	pH	EC (μScm^{-1})	Bulk density ($g\ cm^{-3}$)	Sand	Silt	Clay	Textural class
(South East)	3000-3200	5.98	0.37	1.35	36.10	34.20	29.70	Clay Loam
	3200-3400	5.61	0.28	1.28	29.87	45.45	24.68	Loam
	3400-3600	5.26	0.24	1.19	23.90	60.50	15.60	Silt Loam
(South West)	3000-3200	6.72	0.51	1.31	35.30	33.60	31.10	Clay Loam
	3200-3400	6.51	0.29	1.16	31.08	46.95	21.97	Loam
	3400-3600	6.01	0.19	1.08	25.36	61.62	13.02	Silt Loam

4.Natural regeneration status of *Betula utilis* in Sindh Forest Division

The data pertaining to regeneration status of *Betula utilis* is presented under sub heading of number of recruits, number of un-established regeneration, number of established regeneration, height of un-established regeneration, weighted average height, establishment index, stocking index, establishment stocking per cent and regeneration success percent.

4.1 Recruits (ha^{-1})

The data presented in Table 3 exhibited a greater variation with respect to number of recruits of *Betula* recorded along the altitudinal gradient in the selected sites at Sindh Forest Division. On South Eastern slope the maximum and minimum number of recruits (1375 and 593 ha^{-1}) were present at middle and upper altitudinal gradients respectively. Similarly on the South Western aspect while the maximum number of recruits (1368 ha^{-1}) were again recorded on middle altitude. The minimum number of recruits (656 $ha^{-}1$) were recorded at upper altitudinal gradient (Fig. 2).

Fig.2 Recruits of *Betulis utilis* at Sindh Forest Division

4.2 Un-established regeneration (plants ha^{-1})

The maximum and minimum number of un-established regeneration (344 and 187 plants ha^{-1}) on the South Eastern aspect was recorded at middle and upper altitudinal gradients (Table 4). On South Western aspect while maximum number of un-established regeneration (354 plants ha^{-1}) was recorded on middle altitudinal gradient the minimum (197 ha^{-1}) number of un-established regeneration was recorded at upper altitude (Fig. 3).

Fig.3 Unestablished regeneration at Sindh Forest Division

4.3 Established Regeneration (plants ha^{-1})

The appraisal of data (Table 3) further reveals that South Eastern at aspect Sindh Forest Division exhibited maximum number of established *Birch* regeneration (188 plants ha^{-1}) at middle altitude (3200-3400m) and minimum (37 plants ha^{-1}) at upper altitudinal gradient (3400-3600m). On South Western aspect the maximum number of established regeneration (191 plants ha^{-1}) was recorded on middle altitudinal gradient (3200-3400m) and minimum (62 plants ha^{-1}) at upper altitudinal gradient (3400-3600m) (Fig 4).

Fig.4 Established regeneration at Sindh Forest Division

Table 3: Natural regeneration status of *Betula utilis* across the available aspects and altitudinal gradients in *Betula* dominant tree stands at Sindh Forest Division

Site/Aspect	Altitude (masl)	Recruits (ha^{-1})	Un-established regeneration (ha^{-1})	Established regeneration (ha^{-1})	Height of un-established regeneration (m)
Sindh forest division (South East)	3000-3200	937.50	218.75	125.00	2.43
	3200-3400	1375.00	343.75	187.81	4.70
	3400-3600	593.75	187.50	37.50	1.71
Sindh forest division (South West)	3000-3200	968.75	215.63	135.00	2.62
	3200-3400	1368.00	353.75	190.63	4.94
	3400-3600	656.25	196.88	62.50	1.88

5 Pheno-phases of *Betula utilis* at different altitudes in Sindh Forest Division

The data in Table 4 summarizes Pheno-phases and reproductive behaviour of *Betula utilis* along the altitudinal gradient in the selected sites at the selected forest division. The results envisage that the phenological events of the species overlap with each other. The bud set starts from 1st to 10th May followed by bud burst from 05th to15th May, flowering from 10th to 20th May, leaf initiation from 15th to 25th May, seed formation from 1st to 10th June, seed maturation from 10th to 20th September and leaf fall from 25th September to 10th October at lower altitude. The observations revealed that vegetative and reproductive phases at this altitude were completed in 5 months and 10 days.

The vegetative and reproductive phases of *Betula utilis* were observed to be delayed by some days at the middle altitudinal gradient. The bud set at this altitude started from 5th to 15th May followed by bud burst from 10th to 20th May, flowering from 15th to 25th May, leaf initiation from 20th to 30th May, seed formation from 5th to 15th June, seed maturation from 15th to 25th September. The leaf fall started from 15th of September and prolonged to 30th September. The vegetative and reproductive phases at this altitude were completed in 4 months and 25 days.

Similarly at upper altitudinal gradient pheno-phases were further delayed with bud set starting from 10th to 20th May followed by bud burst from 15th to 25th May, flowering from 20th to 30th May, leaf initiation from 25th May to 05th June, seed formation from 10th June to 20th June, seed maturation from 25th September to 10th October. The leaf fall at this altitude was preponed by 15 days earlier from 5th of September and culminated for 10 days up to 10th of September. The phenodynamics and reproductive phases at this altitude were completed in 4 months and 15 days.

Reproductive and phenophases of *Betulis utilis*

Table 4: Pheno- phases of *Betula utilis* across the available aspects and altitudinal gradient in *Betula* dominant tree stands at Sindh Forest Division

Reproductive and vegetative phases	Altitudes (amsl)		
	3000-3200	**3200-3400**	**3400-3600**
Bud set	01-10 May	5-15 May	10-20May
Bud burst	05-15 May	10-20May	15-25 May
Flowering	10-20 May	15-25May	20-30May
Leaf Initiation	15-25 May	20-30May	25 May-5 June
Flowering dehiscence (Male)	15-25 May	20-30May	25 May-5 June
Seed formation	1-10 June	5-15 June	10-20June
Seed maturation	10-20 Sep	15-25 Sep	25 Sep-10 Oct
Leaf tint	15-25 Sep	5-15 Sep	5-10Sep
Leaf fall	25 Sep.-10 Oct.	15-30Sep	10-25 Sep

5. Propagation of *Betula utilis* through seeds

The seeds of *Betula utilis* are winged measuring around 0.5 to 0.7mm in length. The average weight per 100 seeds was 0.47g with the average number of 1872.87 seeds g^{-1}. The

seeds collected just before their dispersal were sown in the polybags in nursery at Faculty of Forestry at Benhama, SKUAT-Kashmir in March 2017. The cleaned seeds were subjected to stratification for the period of 0, 30, 60 and 90 days 4±2 ^{o}C. The results on germination studies recorded is presented in Table 5 under following headings.

5.1 Germination percentage (%) and Germination energy (%)

The data results revealed that germination of seeds commenced eight (8) days after the sowing in the nursery and was completed in 43 days. The maximum germination of 89.11% was recorded in the seeds subjected to 90 days stratification while minimum of 47.33% was recorded under control. The germination energy of seeds also showed the similar trend with maximum germination of 38.22 in seeds stratified for 90 days and minimum of 21.88 under control.

Table 5. Germination parameters of *Betula utilis* under different treatments

Treatment	Germination (%)	Germination energy
S 0 (Control)	47.33	21.88
S1 (15 days)	53.50	25.70
S2 (30 days)	62.55	30.66
S3 (45 days)	69.30	32.50
S4 (60 days)	77.77	35.22
S5 (75 days)	80.50	36.80
S6 (90 days)	92.40	37.80

5.2 Growth and biomass production of *Betula utilis* in nursery

The perusal of data (Table-6) revealed that the seedlings raised under the influence of 90 days of stratification exhibited maximum plant height of 40.19cm and minimum of 15.33cm was recorded in control. Maximum collar diameter of 5.76mm was exhibited by seedlings raised from seeds stratified for 90 days and minimum in control. Number of leaves also showed the similar trend with maximum 24.67 number of leaves per plant in seedlings stratified for 90 days. Maximum seedling vigor index (SVI) of 35.48 was recorded in seedlings stratified for 90 days and minimum 0f 8.33 under control conditions. Similar trend was observed in leaf area index.

Table 6: Growth performance of *Betula utilis* under nursery conditions

Treatment	Height (cm)	Collar diameter (mm)	Number of leaves seedling^{-1}	Seedling vigour index	Leaf area Index
S0 (Control)	15.33	3.48	13.67	8.33	0.91
S1 (15 days)	20.06	3.75	15.87	13.75	1.09
S2 (30 days)	25.44	3.86	21.33	19.78	1.08
S3 (45 days)	27.95	4.25	21.47	23.32	1.17
S4 (60 days)	31.98	4.44	21.6	28.69	1.18
S5 (75 days)	36.50	5.07	23.27	30.45	1.42
S6(90 days)	40.19	5.76	24.67	35.48	1.49

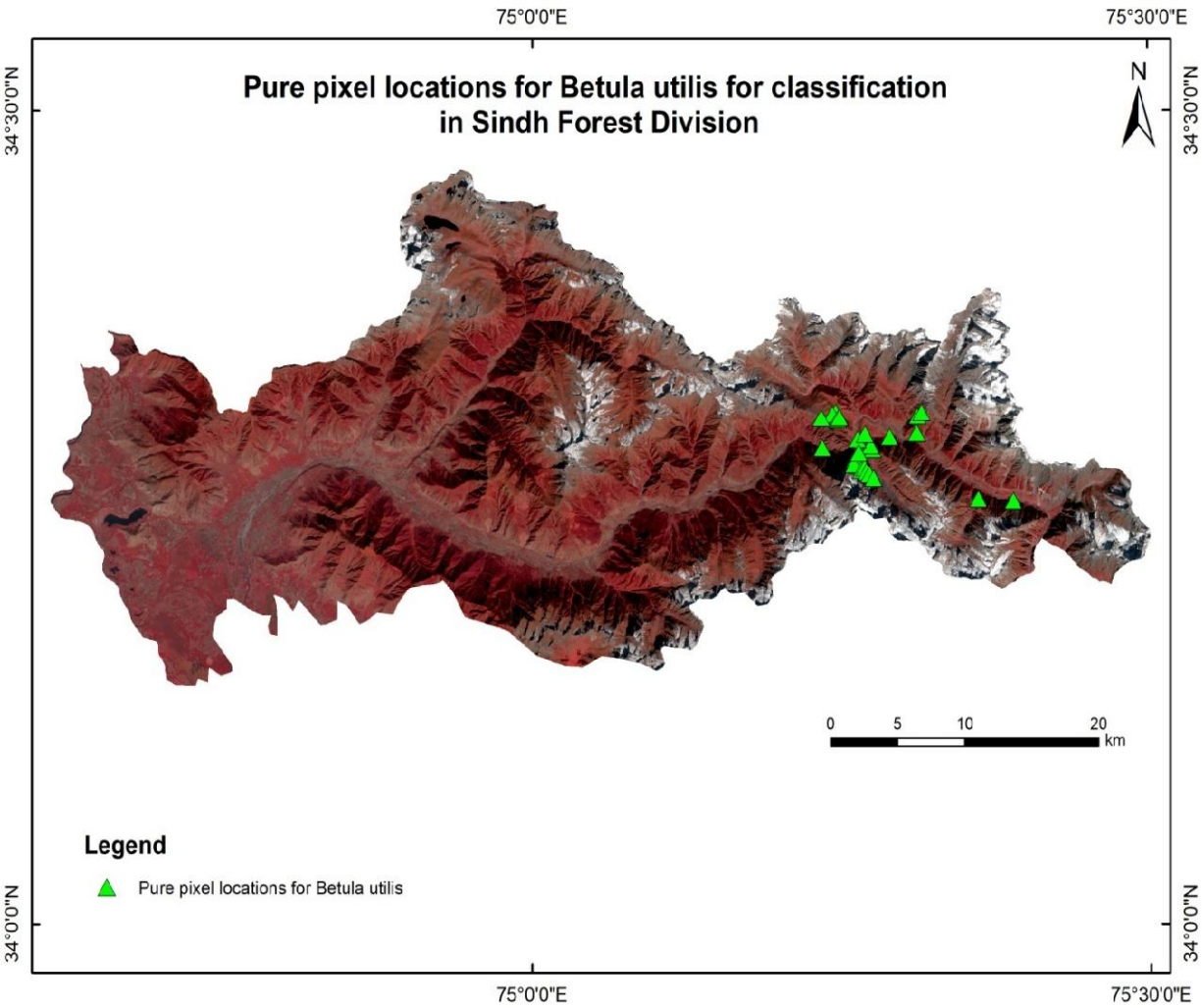
Betula utilis nursery raised under the project

6. Resource mapping

6.1 Collection of points

Groud truth points along with ancillary information collected from the study area.

Y	X	BLOCK	ELEVATION (amsl)
75.362	34.262	Sirbal	3120
75.265	34.285	Thajvas	3090
75.262	34.286	Thajvas	3152
75.261	34.283	Thajvas	3262
75.267	34.279	Thajvas	3305
75.270	34.281	Thajvas	3141
75.271	34.278	Thajvas	3160
75.274	34.277	Thajvas	3127
75.277	34.274	Thajvas	3102
75.276	34.292	Thajvas	3064
75.275	34.294	Thajvas	3001
75.246	34.315	Hangmarg	3254
75.243	34.314	Hangmarg	3382
75.234	34.312	Hangmarg	3378
75.248	34.311	Hangmarg	3303
75.249	34.312	Kazinar	3196
75.313	34.313	Laspather	3099
75.390	34.260	Baltal	2845
75.264	34.298	Shutkari	2671
75.235	34.293	Hangmarg	2515
75.290	34.300	Sonmarg	3100
75.312	34.302	Sonmarg	3300
75.316	34.315	Sonmarg	3500
75.265	34.290	Sonmarg	3100
75.270	34.302	Sonmarg	3300
74.280	34.313	Sonmarg	3500



A) *Betula utilis* signatures developed using remote sensing software

1) Signatures for *Betula utilis* have been developed for the study area.
2) Some refinements are recoding of pixels are required to be done based on pure pixels.

6.2 Works to be accomplished in the next year

1) Generation of Betula distribution map through digital classification technique using signatures developed from pure pixels across the distribution region.
2) Validation of Betula distribution map and accuracy assessment

Sd/=

Dr. P. A. Sofi

Principal Investigator