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Research Paper

Population Assessment and Habitat Distribution Modelling of High Value *Corylus jacquemontii* for *in situ* Conservation in the State of Himachal Pradesh, India

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Corylus jacquemontii is one of the ecologically and economically important high value multipurpose tree in Indian Himalaya Region. Continued over-exploitation and habitat degradation of the species for fodder, fuel, food and medicinal purposes have caused rapid depletion from natural habitats. Therefore, twenty five populations of the *C. jacquemontii* were assessed in Lahaul & Spiti, Kinnaur, Chamba and Kullu districts of Himachal Pradesh. Soil sampled from each population were analyzed. The density of the species was highest in dry slope habitat. Total tree density had a significant positive correlation with organic carbon of soil ($r=0.42$, $P<0.05$ and $n=25$). *C. jacquemontii* seedling density had significant negative correlation with altitude ($r = -0.43$, $P<0.05$ and $n=25$) and pH ($r=-0.60$, $P<0.05$ and $n=50$). Most of the populations had poor regeneration of species. MaxEnt model predicted 3300 Km^2 suitable area for reintroduction of species in Himachal Pradesh. Precipitation of driest peroid emerged as a major factor in determining the distribution of potential habitats of *C. jacquemontii*. Therefore, mass multiplication using seed germination protocol, their establishment in identified habitats and regular monitoring of the habitats with the active participation of local inhabitants, Non-Government Organizations (NGOs) and Forest Department are essentially required.

Keywords: ***Corylus jacquemontii*; Population Assessment; Habitat Distribution Model; Multipurpose; Conservation; Himachal Pradesh, India**

Introduction

The Indian Himalayan Region (IHR) is very well known throughout the world for its representative unique, natural and socio-economically important floristic diversity (Samant *et al*., 1998a; Pant and Samant, 2007). The Himalayan ecosystems support many ecologically and economically important multipurpose tree (MPT) species. Amongst these, *Corylus jacquemontii* Decne. (Indian Tree Hazel), family Corylaceae, is a very well species known ecologically and economically. It is distributed in West Asia, Northeast Afghanistan, Northern India, Northern Pakistan and West Nepal between 1800-3200 m above mean sea level (amsl). In North-Western Himalaya, particularly in Himachal Pradesh, it is found in Chamba, Shimla, Kullu, Lahaul & Spiti and Kinnaur districts, and locally known as Thangi, Bhotiya Badam, Urmuni, Sharoli and Sharod. Tree bark is dark gray in colour, leaves alternate, ovate or obovate, long acuminate, irregularly lobed or toothed, base cordate, silky pubescent on nerves beneath, flowers appear before leaves. Nuts compressed, globose, hard, sheathed by much enlarged lobed, toothed, glandular hairy, spiny, and deep brown bracteoles. The leaves and young shoots are lopped for cattle fodder. The fruits (nuts) are edible and used with parched rice (Samant *et al*., 1996; Pangtey *et al*., 1988; Chauhan *et al*., 2014). The seed oil massage of the species is used for relieving muscular pain (Samant *et al*., 1996; Pangtey *et al*., 1988; Rani *et al*., 2013). Seeds of *C.*

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jacquemontii are traded, and are source of income generation in the area (Samant and Dhar, 1997). Fruit rinds used as dye (Gaur, 2008). The extract obtained from the buds, flowers, leaves, nuts and bark by isolation and purification technique can moisturize skin, and can be used to mobilize fluid in skin tissue and drain the fluid from such tissues (which can reduce puffy eyes) when applied to the skin (Faller *et al*., 2010). In general, economic uses of the species have been mentioned in the research papers (Samant *et al*., 1996; Samant, 1998; Saqib and Sultan, 2005; Singh *et al*., 2009; Rana and Samant, 2011a; Vikram, 2014; Chauhan *et al*., 2014), Ph.D. theses (Rana, 2007; Sharma, 2008; Sharma, 2013), D.Sc. thesis (Samant, 2015) and floras (Brandis, 1924; Gaur, 1999; etc.). None of these workers have studied the assessment of population and physico-chemical properties of soil, and developed habitat distribution model for *C. jacquemontii*.

At national and international levels, studies on the Habitat Distribution Modelling (HDM) or Ecological Niche Modelling (ENM) of the species are available, and have been carried out by Colacicco-Mayhugh *et al*. (2010) on *Phlebotomus alexandri* and *P. papatasi*; Barik and Adhikari (2012) on *Chromolaena odorata*; Singh (2013) on two critically endangered trees, *Shorea johorensis* and *Shorea inappendiculata*; Yang *et al*. (2013) on *Justicia adhatoda*; Jaryan *et al*. (2013) on *Sapium sebiferum*; etc. In India, studies on ENM was initiated by Barik and Adhikari, 2012; Adhikari *et al*., 2012 and ENM were developed by them, based on their experiences all India coordinated project on "Preventing extinction and improving conservation status of threatened plants through application of biotechnological tools was initiated and about 80 threatened species representing all part of countries were selected habitat distribution models were developed (Adhikari *et al*., 2018). Following these studies, attempts have been also made by various workers in different regions (Lal and Samant, 2017; Samant and Lal, 2015; Banerjee *et al*., 2017; etc.). The ENM helps in identifying the suitable habitats (i.e., very high, high, medium and low potential areas). The above studies have predicted the suitable habitats i.e., very high and high for the growth and development of species. Such studies are essential for the *in-situ* conservation of threatened species. *Corylus jacquemontii* which is one of the multipurpose threatened species of the Indian Himalayan Region, is under tremendous pressure due to its utility as food (edible), fuel, fodder and medicine. Apart from the local inhabitants, the wild animals, birds, insects, etc. also feed on the seeds of the species.

The species re-introduction is a successful ecological techniques for recovering and maintaining the position of dwindled species populations, degraded habitats and ecosystems, (Kuzovkina and Volk, 2009; Zai *et al*., 2009; Rodriguez-Salinas *et al*., 2010; Polak and Saltz, 2011; Adhikari *et al*., 2012; Samant and Lal, 2015). For the successful re-introduction and rehabilitation of species in an ecosystem, a detailed knowledge on the potential habitats of species is essential. Species or habitat distribution models play a crucial role in predicting suitable habitat(s) of the species in *in-situ* conservation and management (Cheng and Xu, 2015; Adhikari *et al*., 2012; Samant and Lal, 2015). A large number of species or habitat distribution modelling methods are available to predict potential distribution area of the species (Guisan and Thuiller, 2005; Elith *et al*., 2006; Ortega-Huerta and Peterson, 2008; Wisz *et al*., 2008). The MaxEnt (Maximum Entropy Modelling) software package (Phillips *et al*., 2006) has been proved as the most effective amongst the tools used for habitat distribution modelling (Elith *et al*., 2006; Merow *et al*., 2013). Assessment of modelling success using Area Under Curve (AUC) and correlation indicate that MaxEnt is one of the best performing habitat distribution modelling technique, even with small sample size (Elith *et al*., 2006; Ortega-Huerta and Peterson, 2008).

Continuous over-exploitation and habitat degradation of species for fodder, fuel, food and medicinal purposes have caused rapid depletion of species from natural habitat. Population status and ecological attributes play an important role to make the conservation plans and develop strategies for its long term monitoring and sustainable use. In view of the importance of *C. jacquemontii* as keystone species of forest ecosystem, the present study has been conducted to (i) assess the population of *C. jacquemontii* in Himachal Pradesh, North Western Himalaya; (ii) assess the physico-chemical properties of the soil and correlate with different vegetation parameters; and (iii) develop the habitat distribution model to predict the potential habitat(s) for *in-situ* conservation of *C. jacquemontii*. The study will prove the hypothesis "Population assessment and habitat distribution modelling help in the identification of suitable habitats for *in situ* conservation".

Material and Methods

Extensive and intensive field surveys were conducted in the representative sites of Kullu (2173-2715m), Chamba (2262-2543m), Shimla (2377-3155m), Kinnaur (3050m) and Lahaul & Spiti (2621m) districts of Himachal Pradesh, North Western-Himalaya. The survey and sampling of the populations were done between 30.97873°N to 33.11292°N latitudes and 76.16792°E to 78.34434°E longitudes. The climate and soil varies from place to place.

Sampling Methods

Total 25 populations of *C. jacquemontii* were assessed during 2013-2017. The latitudes, longitudes for each population were obtained with hand held Global Positioning System (Garmin Oregon 550). In the sites/ habitats representing *C. jacquemontii*, a plot of 50×50m was laid. Within this plot, trees, saplings and seedlings were sampled by randomly laid 10 quadrats of 10×10m, shrubs by 20 quadrats of 5×5m and herbs by 20 quadrats of 1×1m (Curtis and Mc Intosh, 1950; Greig-Smith, 1957; Mueller-Dombois and Ellenberge, 1974; Samant *et al*., 2002; Joshi and Samant, 2004). Method of Species-Area Curve was used to determine the size and number of quadrats following Misra (1968), Kershaw (1973), Dhar *et al*. (1997) and Samant and Joshi (2004). The circumference at breast height (cbh at 1.37m from ground level) was measured for each individual tree. The individuals were considered trees (cbh >31.5 cm), saplings (cbh 10.5-31.4 cm) and seedlings (<10.5 cm) based on cbh. From each site, samples of each species were collected and identified with the help of floras (Polunin and Stainton, 1984; Chowdhery and Wadhwa, 1984; Aswal and Mehrotra, 1994; Dhaliwal and Sharma, 1999; and Singh and Rawat, 1999) and research papers and thesis (Samant *et al*., 1998a, 2007; Samant, 2015). Sampling of the populations was done in each site during 2013-17 in a peak season of growth *i.e*., Mid June to September. Data was analyzed statistically using MS-Excel 2007. Pearson Correlation Coefficient was used to interpret the variation.

Soil Sampling and Analysis

During the surveys and sampling of population in each site/plot, soil was cored up to 20 cm depth, soil samples (05 Nos.) one from center and four from four corners were randomly collected, mixed together and a composite sample weighing 200g of the homogenized soil was collected in airtight polythene bags. The packed air tight soil samples were brought to the laboratory for the analysis of physico-chemical properties (Rana and Samant, 2011b). The pH of the soil was measured. Soil was air dried, sieved with 2 mm mess and used for the analysis of total nitrogen, organic carbon, and organic matter, available phosphorous and available potassium (Allen, 1974; Olsen, 1954; Jackson, 1958).

Habitat Distribution Modelling

Twenty five (25) primary and three (03) secondary distributional records (Sharma, 2013; Rana, 2007) of the species were collected through field surveys and review of literature. The coordinates of the locations were recorded in decimal degree to an accuracy of 5-10 m by using a Global Positioning System (Garmin Oregon 550). Remotely sensed data on elevation and bioclimatic variables (Hijmans *et al*., 2005) in highest resolution (*i.e*., ~1 km) were downloaded in BIL format, converted to ASC II raster grids and rescaled to ~250 m resolution in Arc GIS 9.3 (http//www. Worldclim.org).

Auto-correlation among the predictor variables was identified as source of error. Keeping in view this, Ecological Niche Modelling (ENM) tools 1.4.1 were downloaded (www.activestate.com) and used to check autocorrelation among the predictor variables before running the model. Since, autocorrelation was observed between 8 variables, therefore, only 13 variables out of 20 were ultimately selected for modelling taking into consideration the species ecology and the importance of extreme environmental conditions (Jaryan *et al*., 2013).

For habitat modelling, model was developed using Maximum Entropy Modelling (Maxent version 3.3.3k, Phillips *et al*., 2006). Twenty eight (28) species distribution records and 13 bioclimatic variables were used for predicting the suitable habitat model. Twenty (20) replicate effects with cross-validated replicate run type with 10 percentile training presence were used for the validation of model robustness. In the replicated runs, we employed cross validation technique where samples were divided into replicate folds and each fold was used for test data. Other parameters were set to default as the program was already calibrated on a wide range of species datasets (Phillips and Dudík, 2008). From the replicated runs, average maximum, minimum, median and standard deviation were generated. Based on Area Under Curve (AUC) value, the quality of model was evaluated and graded following Thuiller *et al*. (2005) as poor (AUC<0.8), fair (0.8<0.9), good (0.9<0.95) and very good (0.95<1.0). The output generated predicts suitable habitats for the species. Further, potential areas of distribution were categorized into five classes *i.e*., very-high (0.70-1), high (0.50-0.70), medium (0.30-0.50), low (0.10-0.30) and very low (0-0.10) based on logistic threshold of 10 percentile training presence (Adhikari *et al*., 2012; Barik and Adhikari, 2012). Maxent version 3.3.3e and Diva GIS ver. 7.3 were used to generate predictive maps of species distribution and potential areas for reintroduction.

Results

Population Characterstics

Of the total 25 populations of *C. jacquemontii* assessed between 30.97873° N to 33.11292° N latitudes and 76.16792° E to 78.34434° E longitudes in Kullu, Chamba, Shimla, Kinnaur and Lahaul & Spiti districts, 13 populations were represented by shady moist habitat, followed by moist slope (6), dry slope and bouldary (3, each) habitats, respectively. Maximum populations were represented by north-west aspect (9), followed by south-west and north-east (5, each), south and west (2, each), and north and south-east (1, each) between 2173-3155 m (Table 1).

Population Ecology

Overall, site-wise species richness, density, Total Basal Area, species diversity and concentration of tree, shrub and herb layers have been presented in table 2. Richness of trees was ranged from 2-8, shrubs 0-19 and herbs 6-42. Maximum richness of trees was recorded in GHNP-2 and GHNP-3 populations (8, each), followed by Chalali and Ranikot (7, each) and GHNP-4, Mindal, Shakti-3, Chambi and Chanju-1 (6, each) populations. Maximum richness of shrubs was recorded in GHNP-4 population (19), followed by GHNP-3 (16), GHNP-2 (15), Shakti-2 (13) and GHNP-1 (12) populations. Maximum richness of herbs was recorded in Khadapathar and Chanju-1 (42, each) populations, followed by Baggi Thach (38), Chambi and GHNP-2 (35) and Ranikot (29) populations.

Density of *C. jacquemontii* was ranged between 30-230 individual ha^{-1}. The total tree density was ranged from 120-470 Ind ha^{-1}. The total tree density was recorded maximum in GHNP-3 (470 Ind ha^{-1}) population, followed by GHNP-4 and Shakti-3 (400 Ind ha^{-1}, each), Purthi (370 Ind ha^{-1}), and GHNP-2, Bombal and Samana (340 Ind ha^{-1}, each) populations. The density of *C. jacquemontii* was ranged from 30-230 Ind ha^{-1}. Maximum density of *C. jacquemontii* was recorded in Gref Junction (230 Ind ha^{-1}) population, followed by Bombal (220 Ind ha^{-1}), Purthi (210 Ind ha^{-1}) and Baggi Thach, Shakti-2, Shakti-3, Kuthar and Samana (120 Ind ha^{-1}, each) populations.

The Total Basal Area (TBA) was ranged from 0.57-26.47 m^2 ha^{-1}. Maximum TBA was recorded in GHNP-2 (26.47 m^2 ha^{-1}) population, followed by Gref Junction (17.38 m^2 ha^{-1}), GHNP-3 (16.31 m^2 ha^{-1}), Shakti-3 (16.11 m^2 ha^{-1}), and Mindal (15.27 m^2 ha^{-1}) populations. The basal area of *C. jacquemontii* was ranged from 0.03-17.08 m^2 ha^{-1}. Maximum basal area of *C. jacquemontii* was recorded in Gref Junction (17.08 m^2 ha^{-1}) population, followed by Bombal (11.26 m^2 ha^{-1}), Mindal (8.53 m^2 ha^{-1}), Samana (6.21 m^2 ha^{-1}), and GHNP-3 (5.90 m^2 ha^{-1}) populations (Table 2). *Acer acuminatum* (10.84%), *Abies pindrow* (7.76%), *Juglans regia* (7.15%), *Picea smithiana* (5.43%), *Aesculus indica* (4.42%) and *Prunus cornuta* (4.30%) were the major associated species recorded among the populations.

The total shrub density was ranged from 0-2360 Ind ha^{-1}; it was maximum in GHNP-2 (2360 Ind ha^{-1}) population, followed by GHNP-4 (2330 Ind ha^{-1}) and Shakti-2 (1800 Ind ha^{-1}) and Shakti-3 (1620 Ind ha^{-1}) populations. The total herb density was ranged from 6.9-61.5 Ind m^{-2}; it was maximum in Chambi (61.50 Ind m^{-2}) population, followed by GHNP-2 (56.05 Ind m^{-2}), GHNP-4 (55.20 Ind m^{-2}) and GHNP-1 (53.12 Ind m^{-2}) populations.

Table 1: Physical characteristics of *Corylus jacquemontii* populations in Himachal Pradesh, North-Western Himalaya

Population	Habitat	Latitude (°N)	Longi-tude(°E)	Alti-tude(m)	Aspect	Associated Tree Species
GHNP-1	Shady moist	31.74	77.40	2173	NE	*Aesculus indica, Celtis australis, Acer acuminatum*
GHNP-2	Shady moist	31.75	77.40	2330	NW	*Pinus wallichiana, Lyonia ovalifolia, Pyrus pashia, Acer cappadocicum, Celtis australis, Rhododendron arboreum, Picea smithiana*
GHNP-3	Shady moist	31.75	77.38	2350	NW	*Aesculus indica, Acer acuminatum, Prunus cornuta, Celtis australis, Juglans regia, Lyonia ovalifolia, Picea smithiana*
GHNP-4	Shady moist	31.75	77.37	2450	NW	*Aesculus indica, Acer acuminatum, Rhus wallichii, Populus ciliata, Abies pindrow*
Mindal	Dry slope	32.99	76.43	2262	NE	*Corylus ferox, Juglans regia, Acer acuminatum, Fraxinus xanthoxyloides, Celtis australis*
Baggi Thach	Shady moist	31.82	77.40	2600	SW	*Acer acuminatum, Prunus cornuta, Ulmus wallichiana*
Shakti-1	Bouldary	31.79	77.50	2530	NW	*Acer cappadocicum, Juglans regia*
Shakti-2	Dry slope	31.79	77.52	2650	S	*Juglans regia, Prunus cornuta*
Shakti-3	Shady moist	31.79	77.47	2370	SE	*Aesculus indica, Celtis australis, Juglans regia, Morus serrata, Populus ciliata*
Kuthar	Moist Slope	32.76	76.45	2621	NE	*Juglans regia, Pinus wallichiana, Salix daphnoides, Prunus cornuta*
Rahuli	Bouldary	32.84	76.34	2543	W	*Corylus ferox, Fraxinus xanthoxyloides, Juglans regia, Acer acuminatum*
Purthi	Dry slope	32.91	76.47	2445	W	*Cedrus deodara, Fraxinus xanthoxylodis, Pinus wallichiana*
Bombal	Shady moist	32.96	76.42	2341	SW	*Cedrus deodara, Fraxinus xanthozyloides, Corylus ferox, Acer acuminatum*
Gref Junction	Shady moist	33.11	76.37	2436	NW	*Cedrus deodara*
Rakkchum	Bouldary	31.40	78.34	3050	SW	*Acer acuminatum*
Chalali	Moist slope	31.36	77.70	2377	NW	*Picea smithiana, Quercus glauca, Rhus wallichii, Acer acuminatum, Prunus cornuta, Abies pindrow*
Bahli	Moist slope	31.36	77.69	2390	NW	*Quercus glauca, Picea smithiana, Abies pindrow, Betula alnoides*
Jalog	Shady moist	31.23	77.96	3155	SW	*Abies pindrow Acer acuminatum, Quercus floribunda*
Khadapathar	Moist slope	31.12	77.62	2654	NW	*Abies pindrow, Prunus cornuta, Picea smithiana, Pinus wallichiana*
Chambi	Moist slope	30.98	77.54	2722	NE	*Pinus wallichiana, Picea smithiana, Acer acuminatum, Abies pindrow, Quercus floribunda*
Samana	Shady moist	32.03	76.99	2438	S	*Prunus cornuta, Juglans regia, Ulmus villosa*
Tosh Nala	Shady moist	32.02	77.44	2715	NE	*Prunus cornuta, Taxus wallichiana, Acer acuminatum*
Ranikot	Shady moist	32.93	76.17	2536	NW	*Acer acuminatum, Aesculus indica, Abies pindrow, Taxus wallichiana, Juglans regia, Picea smithiana*
Chanju-1	Shady moist	32.70	76.35	2275	SW	*Celtis australis, Acer cappadocicum, Lyonia ovalifolia, Aesculus indica, Quercus floribunda*
Chanju-2	Shady moist	32.70	76.36	2420	N	*Acer acuminatum, Pinus wallichiana, Juglans regia*

Abbreviations used: N = North; E = East; S = South; West = West; NE = North East; NW = North West; SE = South East; SW = South West; and m = meter

Concentration of dominance (Cd) for trees was ranged from 0.18-0.85, shrubs, 0-0.50 and herbs, 0.04-0.66. Maximum Cd for trees was recorded in Gref Junction (0.85) population, followed by Rakkchum

(0.56), Kuthar (0.52) and Bombal (0.46) populations. For shrubs, it was recorded maximum in Samana (0.50) population, followed by Kuthar (0.48), Bahli (0.41) and Tosh Nala (0.39) populations; and for herbs, it was recorded maximum in Bombal (0.66) population, followed by Purthi (0.23), Shakti-2 (0.19), and GHNP-4 and Chalali (0.17, each) populations.

Species diversity (H') for trees ranged from 0.28-1.84, shrubs 0-2.66 and herbs 0.86-3.46. Maximum H' of trees was recorded in GHNP-2 (1.84) population, followed by GHNP-3 (1.83), and Ranikot and Chalali (1.73, each) populations. For shrubs, it was recorded maximum in GHNP-4 (2.66) population, followed by GHNP-3 (2.57), GHNP-1 (2.19) and Baggi Thach (2.15) populations; and for herbs, it was recorded maximum in Baggi Thach (3.46) population, followed by Chambi (3.30), GHNP-2 (3.14) and Jalog (2.91) populations (Table 2).

Amongst habitats, the TBA ($10.08 m^2 ha^{-1}$) and total shrub density (961 Ind ha^{-1}) were highest in the shady moist habitat; total tree density (307 Ind ha^{-1}) was highest in dry slope habitat; and total herb density (38.70 Ind m^{-2}) was highest in the moist slope habitat. The H' of trees (1.46) and herbs (2.81) were highest in moist slope. The Cd of trees (0.39) was highest in bouldary habitat; shrubs (0.34) in moist slope and herbs (0.17) in dry slope habitats, respectively (Table 3). The density of *C. jacquemontii* was highest in dry slope habitat, it was relatively low to shady moist, moist slope and bouldary habitats.

Aspect wise density of *C. jacquemontii* was highest in west aspect (125 Ind ha^{-1}), followed by south (120 Ind ha^{-1}), south-west (108 Ind ha^{-1}), north-east (84 Ind ha^{-1}) and north-west (76 Ind ha^{-1}) aspects.

Regeneration Pattern

Total seedling density was ranged from 0-430 Ind ha^{-1}; it was recorded maximum in GHNP-4 (430 Ind ha^{-1}) population, followed by GHNP-1 (340 Ind ha^{-1}), GHNP-2 (310 Ind ha^{-1}), GHNP-3 and Ranikot (280 Ind ha^{-1}, each), and Rahuli and Mindal (180 Ind ha^{-1}, each) populations. The seedling density of *C. jacquemontii* was ranged from 0-140 Ind ha^{-1}; it was recorded maximum in GHNP-1 (140 Ind ha^{-1}) population, followed by GHNP-3 (70 Ind ha^{-1}), Ranikot (60 Ind ha^{-1}), and GHNP-2, Mindal, Shakti-1 and Shakti-2 (50 Ind ha^{-1}, each) populations. The total sapling density was ranged from 0-290 Ind ha^{-1}; it was recorded maximum in GHNP-2 and GHNP-4 (290 Ind ha^{-1}, each) populations, followed by GHNP-3 (280 Ind ha^{-1}), Shakti-2 (250 Ind ha^{-1}), Rahuli (200 Ind ha^{-1}) and GHNP-1, Shakti-1 and Ranikot (170 Ind ha^{-1}, each) populations. The sapling density of *C. jacquemontii* was ranged from 0-80 Ind ha^{-1}; it was recorded maximum in Shakti-2 (80 Ind ha^{-1}) population, followed by Shakti-1 (70 Ind ha^{-1}), Rahuli and Mindal (60 Ind ha^{-1}, each), GHNP-3 and Baggi Thach (50 Ind ha^{-1}, each) and GHNP-1 (40 Ind ha^{-1}) populations (Table 4).

Physico-chemical Properties of Soil

Among the populations, pH was ranged between 4.56-7.68; it was recorded highest in Rakkchum population (7.68), followed by Bahli (7.55), Shakti-3 (7.29), Rahuli (7.28), Shakti-1 (7.17) and Near Chambi (7.15) populations. Total nitrogen was ranged between 0.09-0.79 %; it was recorded maximum in Shakti-1 and Chanju-2 populations (0.75%, each), followed by Baggi Thach, Bombal, and Chanju-1 (0.70%, each), Shakti-2 and Rakkchum (0.56%, each) and Purthi and Ranikot (0.51%, each) populations. Total organic carbon was ranged between 1.29-8.03%; it was recorded maximum in GHNP-4 population (8.03%), followed by GHNP-3 (8.00%), Bombal (6.98%), GHNP-2 (6.75%), Chanju-1 (6.63%) and Baggi Thach (6.51%) populations. The C/N ratio ranged between 3.97-26.74; it was recorded maximum in Chambi population (26.74), followed byGHNP-3 (24.24), GHNP-4 (21.70), Shakti-3 (20.06), GHNP-1 (19.11) and Bahli (17.74) populations. Maximum available phosphorous was recorded in Samana population (52.98 kg/ha), followed by Bombal (43.79 kg/ha), Khadapathar (20.38 kg/ha) and Rahuli (14.67 kg/ha) populations. Maximum available potassium was recorded in Bombal population (962 kg/ha), followed by Mindal (695 kg/ha), Rahuli (686 kg/ha) and Khadapathar (666 kg/ha) populations (Fig. 1).

Habitat Distribution Modelling

The model calibration test for *C. jacquemontii* yielded satisfactory results (AUC test = 0.938 ± 0.056). Amongst the input thirteen bioclimatic variables, Bio_14 *i.e.*, precipitation of driest period had the maximum influence and contributed 36.8 % to the MaxEnt model. This was followed by Bio_6 *i.e.*, Minimum temperature of coldest period 26.3%,

Table 2: Site wise Species richness, Density, Species diversity and Concentration of dominance of tree, shrub and herb layers of *Corylus jacquemontii* populations

Population	Trees					Shrubs				Herbs			
	RC	Den	Cd	H'	TBA	RC	Den	Cd	H'	RC	Den*	Cd	H'
GHNP-1	4	260	0.29	1.31	4.50	12	990	0.14	2.19	25	53.15	0.09	2.69
GHNP-2	8	340	0.19	1.84	26.47	15	2360	0.19	2.13	35	56.05	0.05	3.14
GHNP-3	8	470	0.18	1.83	16.31	16	1130	0.09	2.57	17	13.00	0.12	2.52
GHNP-4	6	400	0.24	1.61	13.23	19	2330	0.08	2.66	9	55.20	0.17	1.93
Mindal	6	280	0.20	1.70	15.27	6	280	0.18	1.75	19	27.20	0.09	2.65
Baggi Thach	5	300	0.30	1.37	5.71	9	500	0.12	2.15	38	38.10	0.04	3.46
Shakti-1	3	260	0.37	1.04	5.47	9	750	0.14	2.08	9	11.98	0.14	2.08
Shakti-2	3	270	0.37	1.04	4.68	13	1800	0.22	2.00	10	16.03	0.19	1.88
Shakti-3	6	400	0.19	1.71	16.11	11	1620	0.24	1.91	28	30.68	0.09	2.84
Kuthar	5	170	0.52	1.00	1.07	4	270	0.48	1.00	22	24.50	0.08	2.85
Rahuli	5	140	0.23	1.51	0.57	6	360	0.26	1.55	14	6.90	0.08	2.57
Purthi	4	370	0.39	1.14	2.32	3	140	0.34	1.09	6	7.70	0.23	1.64
Bombal	5	340	0.46	1.10	11.81	-	-	-	-	9	28.40	0.66	0.86
Gref Junction	2	250	0.85	0.28	17.38	4	190	0.38	1.16	12	8.90	0.15	2.20
Rakkchum	2	120	0.56	0.64	1.36	5	360	0.20	1.60	20	23.70	0.09	2.72
Chalali	7	260	0.22	1.73	4.45	4	260	0.26	1.37	17	27.50	0.17	2.36
Bahli	5	190	0.26	1.46	3.80	3	290	0.41	1.00	24	39.80	0.09	2.81
Jalog	4	170	0.30	1.28	3.17	-	-	-	-	24	24.40	0.07	2.91
Khadapathar	5	170	0.36	1.26	3.07	3	190	0.34	1.09	42	41.90	0.08	2.77
Chambi	6	210	0.22	1.62	9.92	5	270	0.21	1.58	35	61.50	0.05	3.30
Samana	4	340	0.34	1.19	14.74	2	170	0.50	0.69	21	34.1	0.08	2.74
Tosh Nala	4	160	0.30	1.28	1.02	3	340	0.39	1.02	15	28.8	0.08	2.59
Ranikot	7	250	0.20	1.73	4.97	5	450	0.26	1.46	29	40.5	0.12	2.49
Chanju-1	6	230	0.20	1.70	4.14	3	220	0.35	1.07	42	37	0.07	2.75
Chanju-2	4	230	0.36	1.17	5.52	4	490	0.36	1.19	17	49.5	0.08	2.83

Abbreviations used: RC = Richness; Den = Density (Individual/hectare); Den* = Density (Individual/meter^2); TBA = Total Basal Area (meter^2/hectare); Cd = Concentration of Dominance; and H' = Species diversity

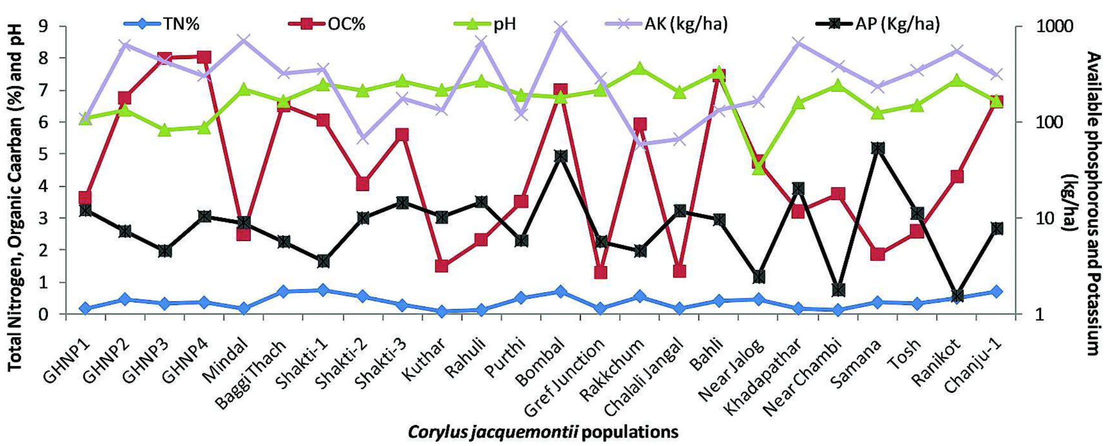

Fig. 1:Physico-chemical properties of soil in different populations of *Corylus jacquemontii*

Table 3: Habitat wise Species richness, Density, Species diversity and Concentration of dominance of tree, shrub and herb layers of *Corylus jacquemontii*

Habitats	Trees						Shrubs				Herbs			
	SR	RC	TBA	Den	Cd	H'	RC	Den	Cd	H'	RC	Den*	Cd	H'
SM	13	5	10.84	301	0.32	1.36	9.09	961	0.25	1.74	21.46	35.44	0.14	2.55
MS	6	6	4.41	205	0.30	1.46	3.67	250	0.34	1.19	30.33	38.7	0.09	2.81
DS	3	4	7.42	307	0.32	1.29	7.33	740	0.25	1.62	11.67	16.98	0.17	2.06
B	3	3	2.47	173	0.39	1.06	6.67	490	0.20	1.74	14.33	14.19	0.10	2.46

Abbreviations used: SR=Site representative; RC=Richness; Den = Density (Individual/ha); Den* = Density (Individual/m^2); TBA = Total Basal Area (m^2/ha); Cd = Concentration of Dominance; and H' = Species diversity; MS = Moist slope; SM=Shady moist; DS=Dry slope; and B = Bouldary

Table 4: Site wise seedling, sapling and total tree density of the *Corylus jacquemontii* populations

Populations	Density (Individual/hactare)					
	Trees		Saplings		Seedlings	
	1	2	1	2	1	2
Baggi Thach	300	120	110	50	80	10
Bahli	190	30	40	10	50	10
Rakkchum	120	80	30	20	30	10
Bombal	340	220	120	20	50	20
Chalali	260	40	40	10	80	10
Chanju-1	230	70	30	10	50	20
Chanju-2	230	60	70	30	140	40
GHNP-1	260	110	170	40	340	140
GHNP-2	340	40	290	-	310	50
GHNP-3	470	110	280	50	280	70
GHNP-4	400	40	290	20	430	40
Gref Junction	250	230	160	20	100	40
Khadapathar	170	40	50	20	110	40
Kuthar	170	120	-	-	-	-
Mindal	280	70	140	60	180	50
Chambi	210	50	110		110	20
Jalog	170	50	-	-	-	-
Purthi	370	210	40	10	20	-
Rahuli	140	40	200	60	180	30
Ranikot	250	30	170	10	280	60
Samana	340	120	-	-	-	-
Shakti-1	260	120	140	70	100	50
Shakti-2	270	120	170	80	90	50
Shakti-3	400	30	250		120	30
Tosh Nala	160	70	60	30	60	-

Abbreviations used: 1 = Total Trees; and 2 = *Corylus jacquemontii*

Table 5: Estimates of relative contributions and permutation importance of the predictor environmental variables to the MaxEnt model

Variable	Name of predictor variable	Percent contribution	Permutation importance
Bio_14	Precipitation of Driest Period	36.8	0.3
Bio_6	Min Temperature of Coldest Period	26.3	21.9
Bio_17	Precipitation of Driest Quarter	26	53
H_dem	Elevation	4.8	6
Bio_4	Temperature Seasonality (Coefficient of Variation)	2.8	9.8
Bio_19	Precipitation of Coldest Quarter	2.1	3
Bio_7	Temperature Annual Range (BIO5-BIO6)	0.6	0.7
Bio_5	Max Temperature of Warmest Period	0.3	0
Bio_2	Mean diurnal range (max temp min temp) (monthly average)	0.1	5
Bio_13	Precipitation of Wettest Period	0	0.3
Bio_18	Precipitation of Warmest Quarter	0	0.1
Bio_3	Isothermality (BIO1/BIO7) *100	0	0
Bio_1	Annual mean temperature	0	0

Bio_17 *i.e.*, Precipitation of driest quarter 26% and H_dem *i.e.*, elevation 4.8%. Bio_17 *i.e.*, Precipitation of driest quarter had the maximum influence on the habitat model considering the permutation importance and contributed to 53%. This was followed by Bio_6 *i.e.*, Minimum temperature of coldest period 21.9%,

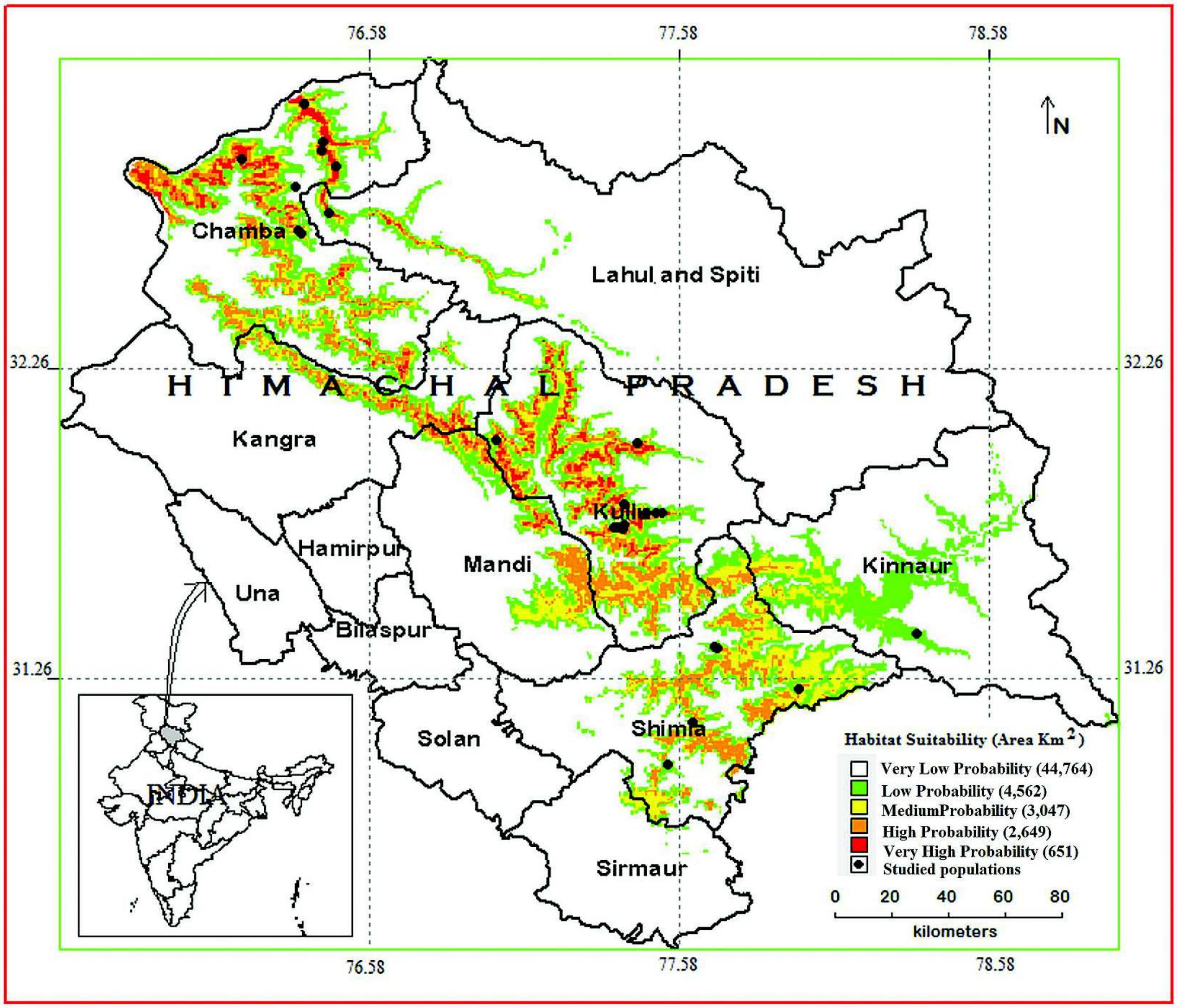

Fig. 2: Habitat suitability and distribution of *Corylus jacquemontii* in Himachal Pradesh, North-Western Himalaya

Bio_4 *i.e.*, Temperature Seasonality (Coefficient of variation) 9.8%, H_dem *i.e.*, elevation 6%, and Bio_2 *i.e.*, Mean diurnal range *i.e.*, maximum temperature-minimum temperature (monthly average) 5% (Table 5).

Potential habitats with high suitability thresholds were distributed in the Kullu, Chamba, Shimla, Mandi, Kinnaur, Kangra and Lahaul & Spiti districts of Himachal Pradesh in North Western biogeographic province of the Indian Himalayan Region. Primary field surveys revealed that the predicted potential habitats were mostly located in the shady moist habitats of Kullu, Chamba, Shimla and Lahaul & Spiti districts of Himachal Pradesh. Of the total geographical area of Himachal Pradesh, the predicted potential area under very high class was 651 km^2 and high suitable class was 2,649 km^2 for the reintroduction of *C. jacquemontii*. Total 3,047 km^2 area was under medium suitability class and maximum area *i.e.*, 4,562 km^2 was recorded under low suitability class (Fig. 2).

Discussions

In the Indian Himalayan Region (IHR), a large number of studies have been carried out on ecology (Dhar *et al*., 1997; Samant *et al*., 1998a, 2002; Joshi and Samant, 2004; *etc*.). However, very few studies are available on population ecology and ENM (Yang *et al*., 2013; Ray *et al*., 2011; Adhikari *et al*., 2012; Barik and Adhikari, 2012; Samant and Lal, 2015; Lal and Samant, 2017). In the IHR, there are a number of species having ecological and economical importance (Samant and Dhar, 1997; Samant *et al*., 1998 a and b, 2007; Rana and Samant, 2010). Among such species, *C. jacquemontii* is very well known for its multipurpose utility and ecological importance. But, due to overexploitation for seeds (nuts), fodder and fuel and habitat degradation, the population of this species is decreasing fast. Therefore, in the present study, 25 populations of *C. jacquemontii* were assessed across the Himachal Pradesh, North-Western Himalaya to; identify the status, regeneration, physico-chemical properties of the soils, and develop habitat distribution model for predicting the suitable area for re-introduction.

The maximum numbers of populations (13) were represented by shady moist habitat indicating that the shady moist habitat forms the best platform for the overall development of the species. The high density of species in dry slope habitat indicated that the dry habitat is suitable for the germination of seeds and development of seedlings and saplings. Similarly, maximum density in west aspect indicated the favorable condition for the establishment and overall development of the species. The high values of basal area for shady moist habitat indicated the availability of sufficient nutrients and the favorable environmental conditions for development. The high species richness in moist slope habitat and south-east aspect also showed the favorable environmental conditions supporting the growth and development of the species. The H' of trees and herbs was maximum in moist slope habitat and it was maximum for shrubs and herbs in south-east aspect indicating environmental conditions are suitable for the germination and overall development of the species. In general, it has been observed that Density, Basal Area, Total Basal Area, Species richness, Species diversity and Concentration of dominance varied from habitat to habitat and aspect to aspect. Overall, among the habitats, representative populations, density, basal area, species richness and H' were highest in moist slope habitat and south-east aspect, hence require priority attention for conservation.

Total tree density showed a significant positive correlation with organic carbon ($r = 0.42$, $P<0.05$ and $n = 25$) of soil. Total basal area ($r = -0.44$, $P<0.05$ and $n = 25$), total tree density ($r = -0.56$, $P<0.05$ and $n = 25$) and *C. jacquemontii* seedling density ($r = -0.43$, $P<0.05$ and $n = 25$) showed significant negative correlation with altitude. Total sapling density ($r = -0.45$, $P<0.05$ and $n = 25$), Total seedling density ($r = -0.56$, $P<0.05$ and $n = 25$) and *C. jacquemontii* seedling density ($r = -0.60$, $P<0.05$ and $n = 50$) had significant negative correlation with pH of soil (Fig. 3).

Regeneration status of a tree species is determined by the presence of saplings and seedlings in the forests (Dhar *et al*., 1997; Samant *et al*., 2002; Joshi and Samant, 2004). In the present study, regeneration i.e., seedlings, 140 Ind ha^{-1}; saplings, 40 Ind ha^{-1} of *C. jacquemontii* was highest in GHNP-1 population, followed by Shakti-2 (seedlings, 50 Ind ha^{-1}; saplings, 80 Ind ha^{-1}), GHNP-3 (seedlings, 70 Ind ha^{-1}; saplings, 50 Ind ha^{-1}), and Shakti-1 (seedlings, 50 Ind ha^{-1}; saplings, 70 Ind ha^{-1}) populations. Great Himalayan National Park (GHNP) and Shakti are the protected areas and regeneration status revealed that this species will continue its dominance in these sites. In Gref Junction, Bombal, Purthi, Baggi Thach, Samana and Kuthar populations, *C. jacquemontii* has highest tree density, but, it had poor or no regeneration (Table 4). Most of the populations had poor regeneration. This could be due to over collection of seeds (nuts) by the local communities and also feeding by the animals, birds and insects. This indicated that species might be replaced by other associated species in near future.

Among the habitat suitability classes, three classes *i.e.*, very high, high and medium suitability classes can be considered for the reintroduction (in situ conservation) of the species. The area under these classes fall in the temperate and sub-alpine zones of Pangi, Chora and Holi Valleys of Chamba district; Sainj, Parvati, Banjar, Lag and Upper Bea Valleys of Kullu district and Barotand Chuhar Valley in Mandi district of Himachal Pradesh, North-Western Himalaya. The model output result predicted that ecological niche coincides with the literature and field geographical distribution. Better population status of the species in areas of higher model thresholds such as Shakti, Baggi Thach, Samana and GHNP in Kullu district and Purthi, Bombal, Kuthar, Mindal and Gref Junction in Pangi Valley of Chamba district revealed that these areas have suitable conditions for the persistence of species. These areas have greatest potential for the occurrence of species and can be

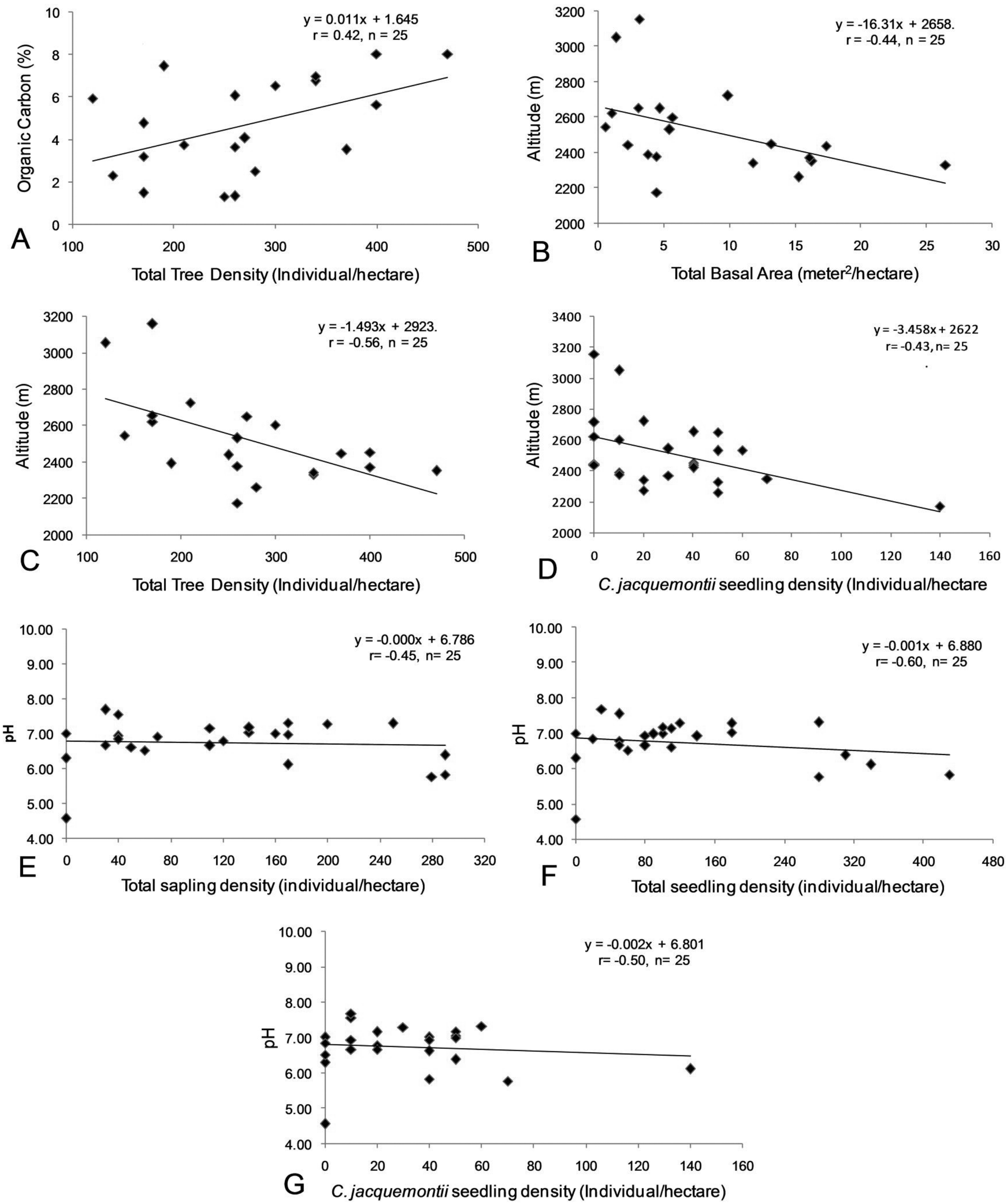

Fig. 3: Correlations between: A. Total Tree Density and Organic Carbon; B. Total Basal Area and Altitude; C. Total Tree Density and Altitude; D. *C. jacquemontii* Seedling Density and Altitude; E. Total Sapling Density vs pH; F. Total Seedling Density vs pH; and G. *C. jacquemontii* Seedling Density vs pH

used for the *in-situ* and *ex-situ* conservation. For the *in-situ* and *ex-situ* conservation, mass multiplication of species through seeds and awareness and active participation of local people, Community Based

Organizations, Non-Government Organizations (NGOs) and Forest Department are essentially required. Precipitation of driest quarter emerged as a major factor in determining the distribution of potential habitats of *C. jacquemontii* in Northwestern Himalaya. The areas identified in the present study for reintroduction of *C. jacquemontii* would help in eco-restoration of degraded forests and habitats, rehabilitating the species population and improving its conservation status. Therefore, the results would be quite useful for conservation of the species and sustainable development of the tribal communities in North Western Himalaya.

The areas identified with the high suitability (*i.e.*, very high, high and medium probabilty areas) revealed high density, regeneration and better physicochemical properties of the soil (*i.e.*, organic carbon, organic matter, total nitrogen, avilable phosphorous and avilable potassium) in most of the populations. On the contrary, the areas falling under low and very low probability revealed relatively low density of trees, seedlings and saplings and poor soil conditions.

Since the seeds of *C. jacquemontii* are economically viable and sold in the local markets at Killar(@ Rs. 1200/- per kg without seed coat), Udaipur (@ Rs. 1300/- per kg without seed coat) and Manali (@ Rs. 1500/- per kg without seed coat), and one of the livelihood options for the poor native communities.

Conclusion

The study provides comprehensive information on population ecology (*i.e.*, species richness, density (trees, saplings, seedlings, shrubs and herbs), Total Basal Area, relative density of *C. jacquemontii,* species diversity, concentration of dominance, physic-chemical properties of the soil, correlations with different parameters and habitat distribution model. The study proved that population ecology and habitat distribution modelling are the prerequisite for species recovery plan. The study would not only help in eco-restoration of the habitats, but also in recovering the species population and improving its in situ conservation.Population ecology showed that most of the populations had low density of species and regeneration was highest in the protected areas in comparison with non-protected areas. Habitat distribution model predicted the limited surface area for occurrence and reintroduction of the species.

C. jacquemonti is one of the important trees of temperate forest ecosystems. It provides provisioning, regulating and supportive ecosystem services to the human and wildlife. Seeds are highly nutritious and rich in protein, and comparable with Almond. The seeds collected from the natural forests and populations are traded in the local and regional markets.

In view of the high value of this species, there is a need to develop conventional (seed germination and cuttings) propagation protocols for mass multiplication, establishment and maintenance of nurseries for quality planting material, and dissemination to the local inhabitants and Forest Department for plantation in the identified habitats with very high and high suitability across the Himachal Pradesh. In addition, there is an urgent need to create awareness among the native communities, Forest Department, NGOs, and other stakeholders on status, soil requirement, economic values and conservation of the species. Conservation and sustainable utilization of the species would serve the local communities for prosperity.

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