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Population Structure of *Juniperus indica* Bertol. along Elevation Gradient in Manang, Trans-Himalayas Nepal

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Abstract

Elevation gradients are complex involving different co-varying factors that influence plant population structure. Along the elevation gradient, subalpine forests are highly vulnerable to natural variation in climate as well as are also under high anthropogenic pressure. The present study aims to study habitat characteristics and regeneration status based on population structure of *Juniperus indica*, a common and highly useful species, along elevation gradient in Manang, north-central Nepal. The distribution range was divided into lower- (3350-3580 m), mid- (3650-3880 m) and higher- (3950-4250 m) elevation bands, where populations were sampled in a total of 54 plots (18 plots per band) of 10 m x 10 m size. In each plot, we recorded aspect, slope and associated species, and number of individuals of studied species classified into seedling, juvenile and adult; and trunk diameter of adult individuals. Altogether, 88 plant species were identified. Plots in the lower- and mid-elevation bands mostly comprised woody shrubs, whereas herbaceous species dominated the higher-elevation band. Mid-elevation band tended to show highest density of seedlings and juveniles, but adult density was high in the plots at lower-elevation band. *J. indica* exhibited almost similar population structure in three bands, with high contribution of juveniles than seedlings and adults. Density-diameter curve was reverse J-shaped, indicating continuous regeneration. Population density is influenced differently by the variations in elevation. *J. indica* in Manang exhibits successful regeneration despite harsh ecological conditions and anthropogenic pressure.

Keywords: Density-diagram curve, Habitat characteristics, Population density, Regeneration

Introduction

Elevation gradients are complex involving many different co-varying factors like topography, soil and climate (Austin et al., 1996). Elevation strongly influences length of growing season and the availability of soil moisture and nutrients (Namgail et al., 2012). Plant species growing along the elevation gradient show considerable variations in structure of their populations and in traits related to their life history and growth. Population structure reflects biological and ecological characteristics of plants which are used to determine regeneration profile (Teketay, 1996). Continuous regeneration is necessary for the long-term persistence of a species population (Thakuri, 2010). Population density of seedlings and juveniles are considered as regeneration potential of a species (Bharali et al., 2012). Abundance of established seedlings and juveniles affects the future composition of forests (Thakuri, 2010). The inclusion of seedlings and juveniles in plant population structures would provide better information about the status of the species at early stage of regeneration. Germination of seeds and establishment of seedlings and juveniles are related to the availability of space and moisture conditions and to adaptation to particular light regimes (Ramakrishnan et al., 1982).

Population dynamics of plant species can be described by demographic properties such as recruitment, mortality and growth. The balance among these properties regulates the dynamics and the structure of a population (Bharali et al., 2012). Plants generally grow and survive in a limited range of the environmental conditions, for example, temperature and light availability and variation in these factors play important roles in shaping the age/size structure and regeneration at different elevations (Block & Treter, 2001; Duan et al., 2009).

Subalpine forest represents the uppermost forest ecosystems along the elevation gradient. They are highly vulnerable to natural variation in climate (Sano et al., 2005) and are also under high anthropogenic pressure (Sharma et al., 2009). Ecological study of subalpine forests in the Nepal Himalaya is very scanty, though some initiatives have been taken in recent time (e.g., Ghimire & Lekhak, 2007; Shrestha et al., 2007; Ghimire et al., 2008; Suwal, 2010; Gaire et al., 2013).

Juniperus indica is an important component of sub-alpine forest of Manang district, northcentral Nepal (Ghimire et al., 2008). The local community and traditional Tibetan practitioner utilize maximum parts of *Juniperus* species, for example, fruits, leaves, stem and barks in traditional medicine to cure kidney, skin and lymph disorders, fever, cough and cold, sores, wounds, and paralysis of limbs (Bhattarai et al., 2006; Ghimire et al., 2008); leaves to burnt for incense by Buddhists. The plant is also used for fencing purpose (Bhattarai et al., 2006). Dried leaves are sold for incense locally. Essential oil obtained from steam distillation of fresh leaves is exported for its use in medicines and cosmetics (Ghimire et al., 2008). Leaves are harvested throughout the year while fruits during July to August.

Studies on Himalayan junipers are confined to essential oil variation in leaf (e.g., Adams & Chaudhary, 1996; Adams et al., 1998), taxonomic determination (e.g., Adams et al., 2009), ethnobotany (e.g., Bhattarai et al., 2006), vegetation analysis (Ghimire et al., 2008), and variation in leaf biomass and fruit outputs (Chapagain et al., 2017). But there are inadequate studies on habitat characteristics, population structure and regeneration potential of *J. indica* which are on high anthropogenic pressure (e.g., destructive practices, such as over-harvesting of leaves for incense and slash-burning to harvest its wood) as well as harsh climatic conditions.

The present study aims to explore habitat characteristics of *J. indica* and predict its regeneration status based on population structure of *J. indica* along elevation gradient in Manang, north-central Nepal, to understand the influences of environmental factors on forest regeneration (Wang et al., 2004). For this, we sampled *J. indica* along an elevation gradient and studied variation in its population ecology. First, the habitat characteristics conditioning differences in plant composition along the elevation gradient were analyzed. Second, variation in population structure and regeneration potential were assessed among populations distributed along the elevation gradient.

Materials and Methods

Study species

Study species *J. indica* is native to high-altitude Himalaya, ranging from Kashmir, India to western Yunnan, China. It is abundant throughout Nepal ranging from 3300 m to 4500 m asl (Press et al., 2000). The plant originates on open and rocky alpine slopes in drier areas. The plant occurs as dwarf woody-shrub at higher elevations above 4,200 m asl and as trees growing at elevational range of 3300-4000 m asl (Ghimire et al., 2008). The leaves are dark grey-green, dimorphic. Mature plants have mostly scale-like leaves which are decussate or sometimes in whorls of 3, closely appressed, 1-3 mm long; while young plants have mostly needle-like leaves, which are borne in whorls of 3 and are 5-8 mm long. Needle-like leaves are also found on shaded shoots of matured plants. The plant is dioecious with male (pollen) and female (seed) cones on individual plants. The pollen cones are sub-globose or ovoid, 2-3 mm long; seed cones are ovoid, berry-like, 6-10 mm long, glossy black when ripe, and contain a single seed. The cones are seen in April to May that mature in October to December. The seeds are mostly dispersed by birds after eating the cones (Ghimire et al., 2008; Chapagain et al., 2017).

Study area

The study area is in Manang District in the north-central part of Nepal (latitude 28.650715 to 28. 675786°N and longitude 84.050218 to 84.056930°E) within altitude range of 3350 to 4250 m asl (Figure 1). The northern part of Manang Valley receives very low annual monsoonal precipitation of ca. 450 mm, whereas the precipitation at southern region (Chame, Manang, at 2680 m asl) remains >1,000 mm (Miehe et al., 2001; Baniya et al., 2009). Similarly, the average annual temperature rests around 6.2°C in the northern trans-Himalayan valley and 11.0°C in the southern region in Manang. There is decreasing moisture from east to west in the upper Manang Valley, and the south-facing slopes are much drier than those facing north (Bhattarai et al, 2004; Ghimire et al., 2008).

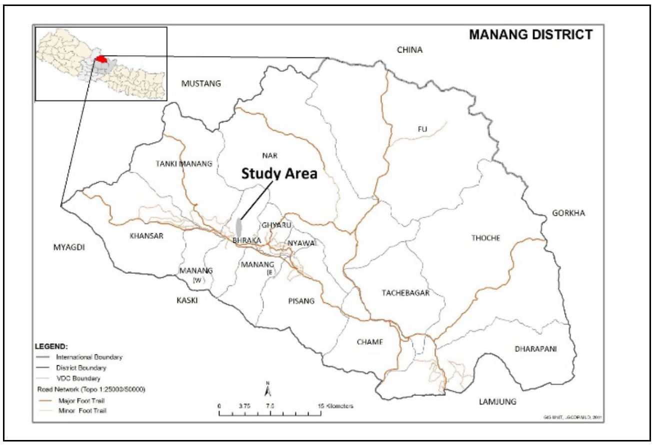

Figure 1. Map of the study area.

Sampling methods

Sampling of *Juniperus indica* population was made in September 2011 in north-eastern part of Manang Valley, using a systematic sampling approach (Chapagain et al., 2017). The study was conducted from Bhraka Village (3350 m asl) of Manang to Ice Lake (4250 m asl) classifying the entire of the distribution range into three elevation bands, based on the harvesting level by local community, lower-elevation band being the nearest and maximum harvest to higher-elevation band being the farthest and least harvest. Lower-elevation band ranged from 3350-3580 m asl, mid-elevation band ranged from 3650-3880 m asl and higher-elevation band ranged from 3950-4250 m asl. In each elevation band, 3 horizontal transects were laid down at *ca*. 75-100 m elevation intervals. In each transect, 6 plots of size 10 m× 10 m were randomly sampled at *ca*. 50-100 m length intervals to record the *J. indica* populations, resulting 54 plots in total. In each sampling plot, individuals of *J. indica* of different size classes were manually counted and recorded separately (Chapagain et al, 2017).

Size classes were recognized related to the growth stage following Chapagain et al. (2017) that was developed from Schemske et al. (1994). The size classes of individuals of *J. indica* were broadly defined according to plant height and/or trunk diameter. Plant height less than 0.1 m and/or trunk diameter less than 1 cm were classified as seedlings. Plant height ranging from 0.1 m to 1.0 m and/or trunk diameter less than 1 cm were classified as juveniles and plant height usually more than 1 m and/or trunk diameter more than 1 cm and also bearing reproductive structure were classified as adult. Adult individuals were recorded for their trunk diameter by using measuring tape. Trunk diameter of adult individuals more than 1-3 m tall was recorded at 25 cm aboveground, while the trunk diameter of adult individuals more than 3 m tall was recorded at 137 cm aboveground.

Latitude, longitude and altitude of each plot were recorded with the help of GPS device. Aspect and slope of each plot were recorded using compass and clinometer respectively. Each 100 m^2 plot was further divided into 4 subplots of 5 m × 5 m size. In each subplot, presence/absence of plant species associated with *J. indica* was recorded. Vouchers of plant species encountered in sampling plots were collected. The vouchers were identified using taxonomic reference (e.g., Polunin & Stainton, 1984; Stainton, 1988) and comparing with specimens housed at Tribhuvan University Central Herbarium (TUCH) and National Herbarium and Plant Laboratories (KATH), Nepal. Herbarium specimens were deposited in TUCH. Nomenclature follows Press et al. (2000).

Data analysis

Habitat characteristics of *J. indica* were evaluated in terms of variation in physical/ topographic variables, and by analyzing patterns of associated species diversity and composition along the elevation gradient. The value of aspect, slope and latitude were combined to calculate potential annual direct incident radiation (PADIR, MJ cm–2 yr–1) by using the formula given by McCune & Keon (2002). Aspect has been folded about the north-south line (rescaling 0-3600 to 0-1800, such that NE = NW, E = W, etc) before calculating PADIR using the following formula: folded aspect = 180 – |Aspect – 180| (McCune & Keon 2002). The formula for calculating PADIR is given by: PADIR = –1.467+1.582×COS(G3) × COS(H3)–1.5×COS(I3) ×SIN(H3) × SIN(G3) - 0.262×SIN(G3) ×SIN(H3) + 0.607×SIN(I3) × SIN(H3); where latitude, slope, and folded aspect are in columns G, H, and I, respectively, all in radians in Microsoft Excel. It gives a relative value (ranging from 0.03-1.11) of how much solar radiation a particular spot receives. Bio-physical variables recorded in *J. indica* growing sites in three elevation bands were compared using one-way ANOVA when the data met assumptions of parametric test (i.e. normal distribution and homogeneity of variance). Bio-physical variables that did not meet the assumption of parametric test even after transformation were treated with non-parametric Kruskal-Wallis tests.

Richness of associated species was calculated as the total number of such species present per plot. Presence-absence data from all the four subplots were combined to calculate abundance of each associated species per plot, in an ordinal scale from 0 (absent from all four subplots) to 4 (presence in all subplots). The abundance data of 88 associate species including *J. indica* from all 54 plots were used to calculate their frequency in lower-, mid- and higher-elevation bands, and overall frequency.

Density and population structure (the relative proportions of seedling, juvenile and adult to total density) of *J. indica* were analyzed for each plot and each elevation band (Bharali et al., 2012). Regeneration potential of *J. indica* was evaluated based on the density of seedlings and juveniles (Shankar, 2001). It was evaluated as the sum of seedling density and juvenile density divided by the density of adults (Endels et al., 2004). In addition, density-diameter (d-d) curve was also developed for individuals with trunk diameter >1 cm to further assess regeneration patterns and population structure of adults. Variation in population density among elevation bands was compared using one-way ANOVA. Liner mixed model (LMM) (McCulloch and Searle, 2000; Verbeke & Molenberghs, 2000) was used to study the effects of elevation on population structure (proportion of life stages - seedlings, juveniles and adults) and regeneration potential. Elevation band and transect nested within elevation band were used as fixed factor and study plot was used as random variable in the model. PADIR and aspect (folded about the north-south line) were used separately in the model as cofactor to account for the effect of insolation and heat load (McCune & Keon, 2002) respectively. LMM procedure fits models a lot of general than those of the generalized linear model (GLM) procedure. LLM also encompasses all models within the variance elements procedure. The major capabilities that differentiate LMM from GLM are that LMM handles correlated and unbalanced data and unequal variances (McCulloch & Searle, 2000). LMM also handles more complex situations in which experimental units are nested in a hierarchy. LMM analyzed the proportions of population structure and regeneration pattern of *J. indica* and also gave significant results for adult proportion and rejuvenation when transects were nested within elevation band. The density-diameter (d-d) curve for adult *J. indica* was analyzed from all study plots to observe the regeneration pattern.

Results and Discussion

Habitat characteristics of J. indica

Juniperus indica was recorded from open dry, rocky and sandy habitats in SE- to SW-facing slopes in upper Manang Valley, with main vegetation type being *Rosa-Berberis-Juniperus* shrubland, subalpine and alpine grasslands, and open forests (mainly of *Pinus wallichiana* at lower elevation), similar to Junicost (2010) and Ueckert (2013), as *Juniperus* mostly prefer limestone and found on dry rocky habitats. The plots at three elevation bands differed in all biophysical variables studied (Table 1). *J. indica* occurred on gentle SW-facing slopes towards higher elevations receiving high solar radiation (Table 1), similar to study of Bhattarai et al. (2006) and Rawat & Everson (2012). Being the root system highly developed and xerophytic nature, the plant has an advantage to establish in dry and rocky substrates. The species is therefore proposed to be particularly suited for afforestation program under xeric ecological conditions of trans-Himalaya (Rawat & Everson, 2012).

Altogether, 88 vascular plant species (representing 64 genera and 37 families), associated with *J. indica*, were identified from the study area, 33 species in lower-elevation band, 49 in mid-elevation band and 72 in higher-elevation band (Table 4). Asteraceae was the dominant family in the study area comprising 16 species within 10 genera, followed by Rosaceae, Gentianaceae, Ranunculaceae, Fabaceae, Scrophulariaceae and Cyperaceae. *Anaphalis*, *Artemisia*, *Carex*, *Juniperus* and *Pedicularis* were the largest genera, each comprising 3 species (Table 5). Subedi (2016) reported 94 species (37 families and 63 genera) associated with population of *J. squamata* in the same study area. Ghimire et al. (2008) reported 19 associated species in *J. indica* forest, representing 14 genera and 11 families within the similar elevation range from 3300 to 4000 m asl. Richness and abundance of associate species were significantly high at higher-elevation plots, the values of which decreased linearly towards lower elevation (Table 1). Vegetation within a landscape is greatly affected by differences in the microclimate, aspect and altitude. The main source of geographic variation in the plant species composition of juniper communities was due to climate and soil texture (Reinoso et al., 2003) and aspect (Bennie et al., 2006).

Frequency of *J. indica* occurrence was estimated to be 68.06%, 61.11%, and 47.22% in lower-, mid- and higher-elevation bands, respectively with an overall frequency of 58.80%. Among the species associated from all sampling plots, *Tanacetum dolichophyllum* (54.17%), *Juniperus squamata* (43.06%), *Rosa sericea* (41.20%), *Berberis aristata* (38.43%), *Carex species* (37.50%), *Tanacetum* sp. (33.80%) and *Cotoneaster microphyllus* (33.33%) exhibited overall high frequency of occurrence (Table 4). The three elevation bands differed, to some extent, in composition of vascular plant species. Plots in the lower- and mid-elevation bands mostly comprised woody shrubs, whereas herbaceous species dominated the plots in the higher-elevation bands. *Carex* spp., *Rosa sericea*, *Tanacetum dolichophyllum*, *Berberis aristata* and *Rhododendron anthopogon* were the most frequent species (with frequency of occurrence >30%) in lower-elevation band. Similarly, *Rosa sericea*, *Cotoneaster microphyllus*, *Tanacetum dolichophyllum*, *Juniperus squamata*, *Berberis aristata*, *Potentilla fructicosa* and *Bistorta macrophylla* were the most frequent species (with frequency >30%) in mid-elevation band, and *Tanacetum dolichophyllum*, *Juniperus squamata*, *Tanacetum* sp., *Lonicera hypoleuca*, *Potentilla peduncularis*, *Rhododendron lepidotum*, *Conyza* sp., *Spiraea canescens*, *Berberis aristata*, *Carex* spp., *Delphinium brunonianum*, *Ajuga lupulina* and *Kobresia gammiei* were the most frequent species (with frequency >30%) in higher-elevation band (Table 4)

Density and size distribution of J. indica

Density of seedling, juvenile and adult of *J. indica* in the entire study area were found to be 4.89 ± 0.67, 6.59 ± 0.95 and 2.26 ± 0.28 (mean±SE) individuals per 100 m^2 plot. The overall density, combining all three size classes was 13.74±1.47 individuals per

Table 1: Bio-physical variables (mean ± SE) recorded in *J. indica* growing sites in three elevation bands (low, mid, high) in Ice Lake area, upper Manang. For elevation, range values are given in the parentheses.

Variables	Low	Mid	High	p
Elevation (m)	3472.83 ± 20.11 (3351-3585)	3761.56 ± 18.70 (3655-3885)	4064.50 ± 20.72 (3947-4197)	<0.001
Aspect (0)	114.06 ± 10.34	136.39 ± 8.52	98.00 ± 8.89	0.021
Slope (0)	46.67 ± 3.96	24.72 ± 2.96	20.28 ± 3.17	<0.001
PADIR (MJ cm–2 yr–1)	0.84 ± 0.04	1.03 ± 0.03	1.00 ± 0.02	0.001
Associate species richness*	23.94 ± 1.54	33.00 ± 2.63	60.44 ± 2.88	<0.001
Associate species abundance	11.56 ± 0.48	15.78 ± 1.42	27.39 ± 1.32	<0.001

Note: Number of vascular plant species associated with *J. indica* per plot. *p* values based on Kruskal-Wallis tests or on one-way ANOVA.

100 m^2 plot or 1374 individuals per ha. Mid-elevation band tended to show high density of seedlings and juveniles, but the results were statistically insignificant (Table 2). On contrary, adult density was high in plots at lower-elevation band.

The total density in the present study is almost three times higher than the value (404 individuals per ha) obtained by Ghimire et al. (2008) in Manang, but almost three times less than the value obtained by Chhetri & Gupta (2007) in Mustang (4250 individuals per ha), Rai (2013) in Langtang region (3500 individuals per ha) and Subedi (2016) in the same study area for *J. squamata* (4850 individuals per ha). However, the elevation trend of population density was almost identical with that of previous reports. In the present study, total density and density of seedlings and juveniles of *J. indica* were found to be high at mid elevation (3650-3880 m asl), but the density of adult trees was high at lower elevation (3350-3580 m). Ghimire et al. (2008) also recorded the total density of *J. indica* to be highest at 3500-3800 m asl (516.66 individuals per ha), followed by 3800-4000 m asl (375 individuals per ha) and 3300-3500 m asl (320 individuals per ha). Subedi (2016) observed density in low, mid and high elevation bands to be 700, 2,422 and 1,728 individuals per hectare respectively in the same study area for *J. squamata*. The variation in population size of seedlings, juveniles and adults at different elevations may be the results of climatic (especially rainfall and temperature) and edaphic factors (availability of soil water) that are critically important for the successful recruitment, establishment, survival and reproduction of plants (Bharali et al., 2012). There is sharp decline in temperature with the rise of elevation (temperature lapse rate for the western Himalayas is estimated to be 0.6-0.74°C per 100 m elevation raise for various months of the year (Jain et al., 2008). The pattern of decrease in density with elevation can vary with species as biotic interactions, mainly competition, also play a role in growth rate (McPherson & Wright, 1989; Ghimire et al., 2010).

The proportions of seedling, juvenile and adult of *J. indica* in all 54 plots were 0.356, 0.480 and 0.164 respectively. In three elevation bands, *J. indica* exhibited almost similar population structure, with high contribution of juveniles than seedlings and adults (Figure 2). However, proportion of adult was significantly high in lower-elevation band (LMM $F_{2, 44} = 3.425$, $p = 0.041$, Figure 2, Table 3), whereas proportions of seedling and juvenile tended to be high in mid- and higher-elevation bands (but the results were statistically insignificant, Figure 2 and Table 3). But significantly higher value of rejuvenation (expressed as the sum of seedling and juvenile density divided by the density of the adults) at mid- and higher-elevation bands compared to lower-elevation (LMM $F_{2, 44} = 3.280$, $p = 0.047$, Figure 2, Table 3) signifies potentially higher regeneration of *J. indica* towards mid- and higher elevations.

LMM analyses also gave significant results for adult proportion and rejuvenation when transects were nested within elevation band (Table 3), indicating that these parameters spatially varied within the same elevation band. However, in either of the case, the effect of aspect or PADIR (both used separately as covariate in the model) were not significant, indicating SE and SW gradient or incident radiation did not affect population structure. Among the remaining predictor variables considered in this study, richness and abundance of associate species also did not show significant relationship with either

Table 2: Density (number of individuals per 10 × 10 m plot) of *J. indica* recorded in three elevation bands in Ice Lake area, upper Manang valley. Data shown are mean ± SE.

	Low	Mid	High	F2,53	p
Seedling	5.39 ± 1.35	6.22 ± 1.39	3.06 ± 0.39	1.484	0.236
Juvenile	7.06 ± 1.63	8.39 ± 2.20	4.33 ± 0.64	0.582	0.563
Adult	3.17 ± 0.52	1.50 ± 0.27	2.11 ± 0.57	2.536	0.089
Total	15.61 ± 2.32	16.11 ± 3.45	9.50 ± 1.15	1.894	0.161

Note: *F* and *p* values based on one-way ANOVA.

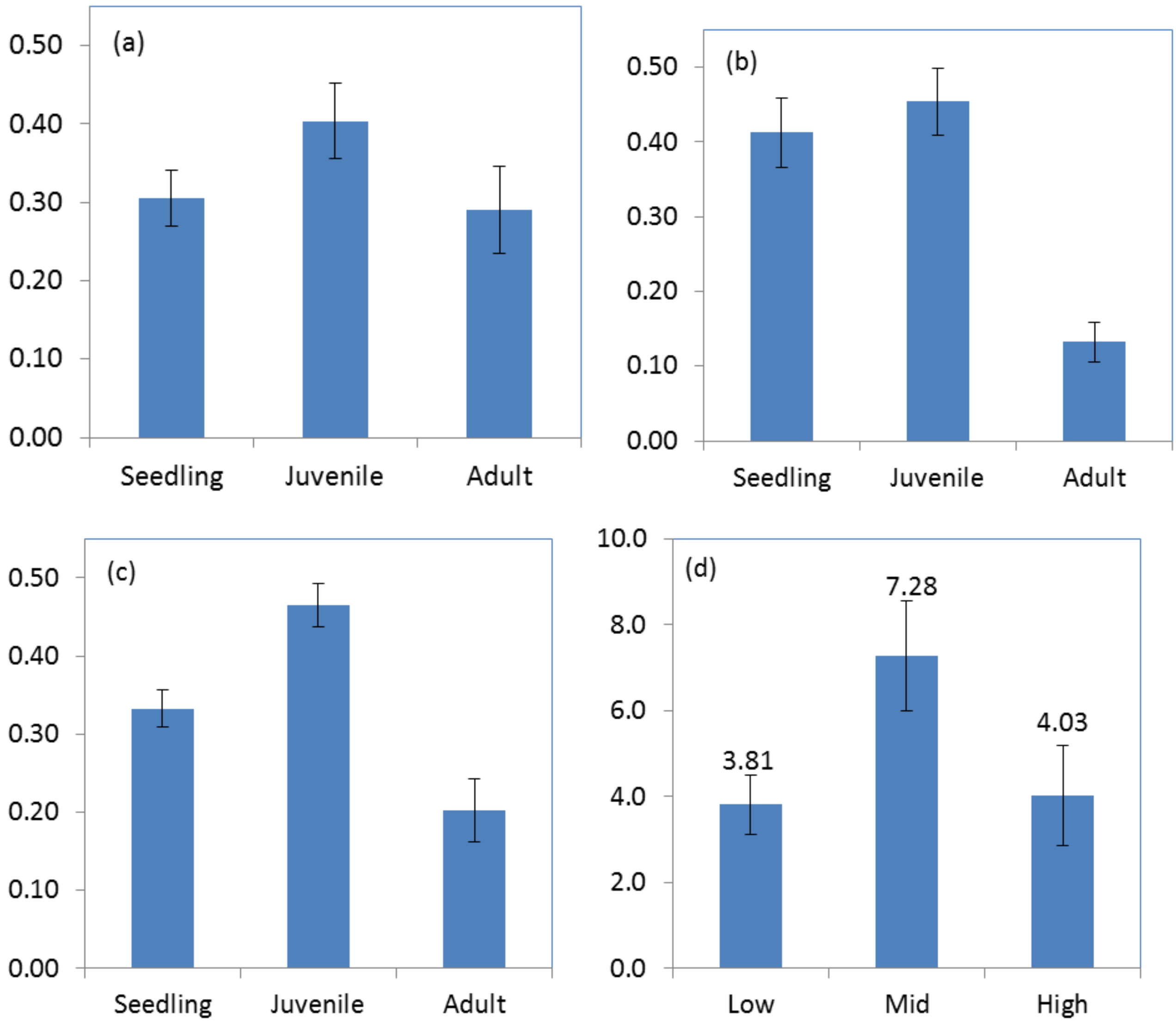

Figure 2: Proportions of Population structure [proportions (mean ± SE) of seedling, juvenile and adult] and regeneration pattern of *J. indica* at three elevation bands in Ice Lake area, upper Manang valley: (a-c) Population structure at three elevation bands (a – lower-elevation, b – mid-elevation, and c – higher-elevation), (d) rejuvenation expressed as the sum of seedling and juvenile density divided by the density of adults.

Table 3: Results of liner mixed model (LMM) showing the effects of elevation band and transect (nested within elevation band) as fixed factor and aspect (folded about the north-south line) as cofactor on size class proportions and rejuvenation of *J. indica*. Position of plots was used as random variable in the LMM.

	Seedling proportion			Juvenile proportion				
Source of variation	Ndf	Ddf	F	P	Ndf	Ddf	F	P
Elevation band	2	44	1.423	0.252	2	44	0.632	0.536
Transect (elevation band)	6	44	0.711	0.643	6	44	0.792	0.581
Aspect	1	44	1.526	0.223	1	44	0.297	0.589
	Adult proportion			Rejuvenation				
Source of variation	Ndf	Ddf	F	P	Ndf	Ddf	F	P
Elevation band	2	44	3.425	0.041	2	44	3.280	0.047
Transect (elevation band)	6	44	2.678	0.027	6	44	5.037	0.001
Aspect	1	44	3.290	0.077	1	44	.471	0.496

Note: Ndf = numerator df; Ddf = denominator df density of *J. indica* in three size classes or their proportions.

The future community structure and regeneration status of plant species can be predicted from the relative proportion of seedlings, juveniles and adults in the total population (Bharali et al., 2012). The highest contribution of juveniles may be the result of maximum seedlings grown to juveniles. Seedlings and juveniles together constituted about 84.35% of the total population of *J. indica*. This shows good regeneration potential of *J. indica* in the study area.

Some of the previous studies have reported that regeneration potential of *Juniperus* species is generally low (Juan et al., 2003; Otto et al., 2010). The factors considered for explaining low regeneration in *Juniperus* spp. are low production of viable seeds (Juan et al., 2003; Junicost, 2010; Otto et al., 2010), disturbance, increased competition, and absence of suitable dispersal vectors (McPherson & Wright, 1989), and in some dioecious species, low amount of pollen that reaches female individuals resulting in less number of fruits set (Juan et al., 2003). In contrast, our study indicates successful regeneration of *J. indica* in Manang, central Nepal despite harsh ecological conditions. *J. indica* exhibits dioecious or monoecious habit (Adams, 2014). Even in dioecious form, the distribution of male and female adults in most populations was random with no evidence of sex clustering resulting in high reproductive success by high amount of pollen reaching female individuals to produce high number of fruits set and this might be the reason why *J. indica* showed high regeneration potentiality in Manang.

However, regeneration of *J. indica* was comparatively low in lower elevation band, despite higher seed output than in mid and higher elevations. This might be due to several reasons. Firstly, this can be linked to disturbance, as the lower elevation band of the study area is close to settlement area where it received greater human pressure especially from livestock grazing. Secondly, *J. indica* in lower elevation band is associated with *Pinus wallichiana* where dominance of pine needles deposition of later species might have suppressed recruitment and successful establishment of *Juniper* seedlings. Reinoso et al. (2003), for example, observed that maritime juniper woodlands of Spain were affected by pine plantations, where deposition of pine needles reduced recruitment of juniper seedlings and increased their mortality. Junicost (2010) reported that as pines are growing much faster than junipers, they produce massive numbers of easily germinable seeds and modify the microenvironment against other species by deposition of pine needles. Junipers have low germination capacity [e.g., <5% in maritime juniper (Reinoso et al., 2003)] are difficult to propagate from seed and are slow growing which, when coupled with human disturbance and competitive stresses, can make establishment difficult (Forestry commission, 2003).

Increasing proportions of younger individuals of *J. indica* in mid and high elevation band show its capacity to tolerate harsh ecological conditions of higher elevations. Wide elevation amplitude (3300-4500 m within Nepal) together with its capacity to tolerate harsh conditions may enable *J. indica* to be quite successful species to adapt ecological changes. There is evidence that increasing carbon dioxide concentrations in the atmosphere during the last century may be benefitting junipers as they utilize the elevated carbon dioxide concentrations in C3 photosynthetic pathway increasing their distribution and abundance (Mayeux et al., 1991).

Density-diameter (d-d) curve

The density-diameter (d-d) curve for adult *J. indica* from all study plots was nearly reverse *J*-shaped (Figure 3a), where the density of *J. indica* was successively reduced with the increase of trunk diameter. In the lower-elevation band, smaller- and large-sized adult individuals were more or less equally present except for size class >4-6, which had highest density value (Figure 3b); whereas in the mid- and higher-elevation bands, the large-sized adults(>8 cm in mid- and >6 cm in higher-elevation band) were completely absent (Figure 3c,d).

The nearly reverse J-shaped d-d curve for *J. indica*, indicates its continuous regeneration (Vetaas, 2000). Similar reverse J-shaped patterns of population

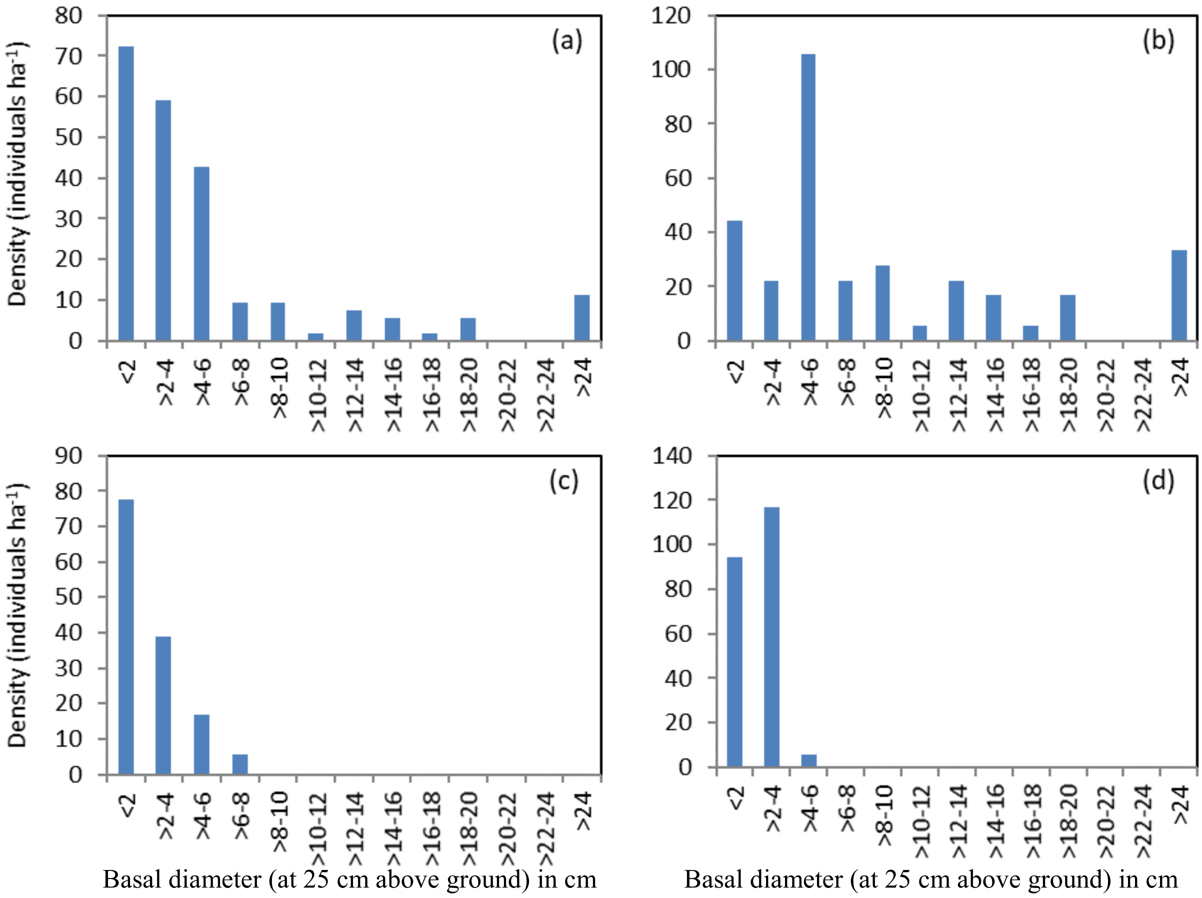

Figure 3: Density-diameter curve for adult *J. indica* in (a) the overall study plots, (b) lower-elevation band, (c) mid-elevation band, and (d) higher-elevation band. Basal diameter (at 25 cm above ground) in cm Basal diameter (at 25 cm above ground) in cm.

structure have been reported for different high-altitude tree species of Manang, central Nepal, such as *Abies spectabilis* (Ghimire & Lekhak 2007), *Betula utilis* (Shrestha et al., 2007), and *Pinus wallichiana* (Ghimire et al., 2010).

Conclusion

Juniperus indica preferred dry and rocky habitats in SE- to SW-facing slopes, along with *Rosa-Berberis-Juniper* shrubland, subalpine and alpine grasslands, and open forests. Above 3800 m on the southern aspect, the forest was comprised of only bushy *J. indica*. Altogether, 88 plant species, associated with *J. indica*, were identified. Lower- and mid-elevation bands mostly comprised woody shrubs, whereas herbaceous species dominated higher-elevation band. Population density of *J. indica* is influenced differently by the variations in elevation. Mid-elevation band tended to show highest density of seedlings and juveniles, but adult density was high in the plots at lower-elevation band. *J. indica* exhibited almost similar population structure in three bands, with high contribution of juveniles than seedlings and adults. However, proportion of adult was high in lower-elevation, whereas proportions of seedling and juvenile tended to be high in mid- and higher-elevations. Density-diameter curve for adult *J. indica* was reverse *J*-shaped, indicating continuous regeneration.

It is concluded that *J. indica* in Manang exhibits higher regeneration at mid- and higher elevation bands indicating plants ability to tolerate adverse environmental conditions as well as a tendency for expansion of its distribution niche towards cooler habitat of high elevation despite high anthropogenic pressure.

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Conflict of Interest

There is no any conflict of interest among the authors.

References

Adams, R. P. & Chaudhary, R. P. (1996). Leaf essential oil of *Juniperus indica* Bertol from Nepal. *Journal of Essential Oil Research*, *8,* 677–680.

Adams, R. P., Thapa, R. K., Agrawal, S. G., Kapahi, B. K., Srivastava, T. N. & Chaudhary, R. P. (1998). The leaf essential oil of *Juniperus recurva* Buch. Ham. ex D. Don from India and Nepal compared with *J. recurva* var. *squamata* (D. Don) Parl. *Journal of Essential Oil Research*, *10*, 21–24.

Adams, R.P. (2014). *Junipers of the World: The Genus Juniperus*. Fourth Edition. Bloomington, USA: Trafford Publishing Co.

Adams, R.P., Chaudhary, R.P, Pandey, R.N. & Singh, L. (2009). *Juniperus recurva* var. *uncinata*, the hooked branchlet juniper, a new variety from Nepal. *Phytologia*, *91*(3), 361-366.

Austin, M. P., Pauses, J. G. & Nicholls, A. O. (1996). Pattern of tree species richness in relation to environment in south-eastern New South Wales Australia. *Australian Journal of Ecology, 21*, 154-164.

Baniya, C.B., Solhøy, T. & Vetaas, O.R. (2009). Temporal changes in species diversity and composition in abandoned fields in a trans-Himalayan landscape, Nepal. *Plant Ecology, 201*, 383-399.

Bennie, J., Hill, M.O., Baxter, R. & Huntley, B. (2006). Influence of slope and aspect on long-term vegetationchange in British chalk grasslands. *Journal of Ecology, 94,* 355-368.

Bharali, S., Paul, A. Khan, M.L. & Singha, L.B. (2012). Impact of altitude on population structure and regeneration status of two *Rhododendron* species in a temperate broad leaved forest of Arunachal Pradesh, India. *International Journal of Ecosystem, 2* (1), 19-27.

Bhattarai K.R., Vetaas O.R. & Grytnes J.A. (2004). Relationship between plant species richness and biomass in an arid sub-alpine grassland of the central Himalayas, Nepal. *Folia Geobotanica, 39*, 57-71.

Bhattarai, S., Chaudhary, R.P. & Taylor, R.S.L. (2006). Ethnobotany of wild Junipers (*Juniperus* species) in Manang district, central Nepal. *Scientific World, 4* (4), 109-112.

Block, J. & Treter, U. (2001). The limiting factors at the upper and lower forest limits in themountain-woodland steppe of northwest Mongolia Joachim Block and Uwe Treter. In Kaennel D.M. and Braker O.U. (Eds.), *the International Conference on Tree Rings and People*, Davos. Proceedings.

Chapagain, A., Chaudhary, R.P. & Ghimire, S.K. (2017). Variation in leaf biomass and fruit output of *Juniperus indica* along an elevation gradient in north-central Nepal. *Banko Jankari (A Journal for Forestry Information of Nepal), 27* (1), 3-10. doi: http://dx.doi.org/10.3126/banko.v27i1.18543

Chhetri, H.B. & Gupta, V.N.P. (2007). A survey of non-timber forest products (NTFPS) in upper mustang. *Scientific World, 5* (5), 89-94.

Duan, R.Y., Wang, X.A., Tu, Y.B., Huang, M.Y., Wang, C., Zhu, Z.H. & Guo, H. (2009). Recruitment pattern of tree populations along an altitudinal gradient: *Larix chinensis* in Qinling mountains (China). *Polish Journal of Ecology, 57* (3), 451–459.

Endels, P., Adriaens, D., Verheyen & Herm, M.

(2004). Population structure and adult performance of forest herbs in three contrasting habitats. *Ecography*, *27*, 225-241.

Forestry commission. (2003). Growing Juniper: Propagation and Establishment Practices. Retrieved from http://www.forestry.gov.uk/pdf/FCIN050.pdf/$FILE/FCIN050.pdf. (assessed 11Nov. 2016).

Gaire, N.P., Koirala, M., Bhuju, D.R. & Borgaonkar, H.P. (2013). Treeline dynamics with climate change at Central Nepal Himalaya. *Climate Past Discussion, 9*, 5941–5976.

Ghimire, B.K. & Lekhak, H.D. (2007). Regeneration of *Abies spectabilis* (D. Don) Mirb. in subalpine forest of Upper Manang, north-central Nepal. In (Eds.) R. P. Chaudhary, T. H. Aase, O.R. Veetas and B. P. Subedi, *Local Effects of Global Changes in the Himalayas: Manang, Nepal* (pp. 139-149). Nepal: Tribhuvan University and Norway: University of Bergen.

Ghimire, B.K., Lekhak, H.D., Chaudhary, R.P. & Vetaas, O.R. (2008). Vegetation analysis along an altitudinal gradient of *Juniperus indica* forest in southern Manang Valley, Nepal. *International Journal of Ecology and Development*, *9*, 20-29.

Ghimire, S. K., Sapkota I. B., Oli, B. R. & Parajuli, R. R. (2008). *Non-Timber Forest Products of Nepal Himalaya: Database of Some Important Species found in the Mountain Protected Areas and Surrounding Regions.*, Kathmandu, Nepal: WWF Nepal Program.

Ghimire, B.K., Mainali, K.P., Lekhak, H.D., Chaudhary, R.P. & Ghimeray, A.K. (2010). Regeneration of *Pinus wallichiana* A.B. Jackson in a trans-Himalayan dry valley of north-central Nepal. *Himalayan Journal of Sciences, 6* (8), 19–26.

Jain, S.K., Goswami, A. & Saraf, A.K. (2008). Determination of land surface temperature and its lapse rate in the Satluj River basin using NOAA data. *International Journal of Remote Sensing, 29* (11), 3091–3103.

Juan, R., Pastor J., Fernandez, I. & Diosdado, J.C. (2003). Relationships between cone traits and seed viability in *Juniperus oxycedrus* L. subsp. *macrocarpa* (Sm.) Ball (Cupressaceae). *Acta Biologica Cracoviensia Series Botanica, 45* (2), 69–78.

Junicost. (2010). *Composition and structure of Juniperus macrocarpa subpopulations*. Retrieved from http://www.junicoast.gr/documents/0000/0048/LIFE_07_NAT_GR_000296_Deliverable_A.3rev1.pdf

Mayeux, H.S., Johnson, H.B. & Polley, H.W. (1991). Global change and vegetation dynamics. In L.F. James, J.O. Evans, M.H. Ralphs and R.D. Child (Eds.), *Noxious Range Weeds*. Boulder, Colorado: Westview Press.

McCulloch, C.E. & Searle, S.R. (2000). *Generalized, Linear, and Mixed Models*, USA: John Wiley and Sons.

McCune, B. & Keon, D. (2002). Equations for potential annual direct incident radiation and heat load. *Journal of Vegetation Science, 13*, 603-606.

McPherson, G.R. & Wright, H.A. (1989). Direct effects of competition on individual juniper plants: a field study. *Journal of Applied Ecology, 26*, 979-988.

Miehe, G. Winiger, M., Böhner, J. & Zhang, Y. (2001). The climate diagram map of High Asia: purpose and concepts. *Erdkunde*, *55*, 94–95.

Namgail, T., Rawat, G.S., Mishra, C., Wieren, S.E. & Herbert, H.T.P. (2012). Biomass and diversity of dry alpine plant communities along altitudinal gradients in the Himalayas. *Journal of Plant Research*, *125*, 93–101.

Otto, R., Krüsi, B.O., Delgado, J.D., Fernández-Palacios, J. M., García-Del-Rey, E. & Arévalo. J.R. (2010). Regeneration niche of the Canarian juniper: the role of adults, shrubs and environmental conditions. *Annals of Forest Science*, *67*(7), 709.

Polunin, O. & Stainton, A. (1984). *Flowers of the Himalayas*. New Delhi, India: Oxford Press.

Press, J.R., Shrestha, K.K. & Sutton, D.A. (2000). *Annotated Checklist of the Flowering Plants of*

Nepal. London: Natural History Museum.

Rai, R. (2013). *Documentation, Promotion and Awareness of Vital Medicinal and Aromatic Plant Species (MAPs) of Langtang Region, Nepal*. The Rufford Small Grants Foundation. Retrieved from http://www.rufford.org/files/10943-1%20Final%20Report.doc

Ramakrishnan P.S., Sukla P.R. and Boojh R. (1982). Growth strategies of trees and their application to forest management. *Current Science, 51*, 448-455.

Rawat, Y.S. & Everson, C.S. (2012). Ecological status and uses of juniper species in the cold desert environment of the Lahaul valley, North-western Himalaya, India. *Journal of Mountain Science, 9*(5), 676-686.

Reinoso, M. & Carlos, J. (2003). *Juniperus oxycedrus* ssp. *macrocarpa* in SW Spain: ecology and conservation problems. *Journal of Coastal Conservation, 9*, 113-122.

Sano, M., Furuta, F., Kobayashi, O. & Sweda, T. (2005). Temperature variations since the mid-18th century for western Nepal, as reconstructed from tree-ring width and density of *Abies spectabilis*. *Dendrochronologia, 23*, 83-92.

Schemske, D.W., Husband, B.C., Ruckelshaus, M.H., Goodwillie, C., Parker, I.M. and Bishop, J.G. (1994). Evaluating approaches to the conservation of rare and endangered plants. *Ecology, 75*, 584-606.

Shankar, U. (2001). A case study of high tree diversity in a sal (*Shorea robusta*) dominated lowland forest of Eastern Himalaya: floristic composition, regeneration and conservation. *Current Science, 81*(7), 776–786.

Sharma, C.M., Suyal, S., Gairola, S. & Ghildiyal, S.K. (2009). Species richness and diversity along an altitudinal gradient in moist temperature forest of Garhwal Himalaya. *Journal of American Science, 5*, 119-128.

Shrestha, B.B., Ghimire, B.K., Lekhak, H.D. & Jha, P.K. (2007). Regeneration of Treeline birch (*Betula utilis* D.Don) forest in a trans-Himalayan dry valley in Central Nepal. *Mountain Research and Development, 27*, 259-267.

Stainton, A. (1988). *Flowers of the Himalayas – a Supplement*. New Delhi, India: Oxford press.

Subedi, P. U. (2016). *Population Structure and Plant Performance of Juniperus squamata Buch.-Ham. ex D. Don along an Elevation Gradient in Manang, Nepal*. (MSc Thesis), Tribhuvan University, Nepal.

Suwal, M. (2010). *Tree Species Line Advance of* Abies spectabilis *in Manaslu Conservation Area, Nepal Himalaya*. (MSc Thesis), Tribhuvan University, Nepal.

Teketay, D. (1996). *Seed ecology and regeneration in dry Afromontane forests of Ethiopia*. (PhD Thesis), Swedish University of Agricultural Sciences, Umea.

Thakuri, P.S. (2010). *Plant community structure and regenerarion of Quercus semecarpifolia Sm. forests in disturbed and undisturbed areas*. (MSc Thesis), Tribhuvan University, Nepal.

Ueckert, D.N. (2013). *Biology and ecology of redberry juniper*. Texas A&M AgriLife Research and Extension Center.

Verbeke, G. & Molenberghs, G. (2000). *Linear Mixed Models for Longitudinal Data*. USA: Springer.

Vetaas, O.R. (2000). The effect of environmental factors on the regeneration of *Quercus semecarpifolia* Sm. in central Himalaya, Nepal. *Plant Ecology, 146*, 137- 144.

Wang, T., Liang, Y.H., Ren, B., Yu, D., Ni, J. and Ma, K.P. (2004). Age structure of *Picea schrenkiana* forest along an altitudinal gradient in the central Tianshan Mountains, northwestern China. *Forest Ecology and Management, 196* (2-3), 267–274.

Table 4: Frequency of occurrence (%) of vascular plant species associated with *Juniperus indica* in different elevation bands

S.N.	Plant species	Family	Frequency of occurrence (%) in different elevation bands			
			Lower-elevation band	Mid-elevation band	Higher-elevation band	Overall
1.	*Ajuga lupulina* Maxim.	Lamiaceae	0.00	1.39	33.33	11.57
2.	*Allium sikkimense* Baker	Amaryllidaceae	0.00	0.00	2.78	0.93
3.	*Anaphalis triplinervis* (Sims) C. B. Clarke	Asteraceae	0.00	0.00	1.39	0.46
4.	*Anaphalis xylorhiza* Sch. Bip. ex Hook. f.	Asteraceae	0.00	26.39	27.78	18.06
5.	*Anaphalis contorta* (D. Don) Hook. f.	Asteraceae	0.00	0.00	13.89	4.63
6.	*Androsace muscoidea* Duby	Primulaceae	0.00	0.00	11.11	3.70
7.	*Androsace tapete* Maxima.	Primulaceae	0.00	0.00	1.39	0.46
8.	*Anemone rupicola* Cambess.	Ranunculaceae	0.00	0.00	12.50	4.17
9.	*Arabidopsis himalaica* (Edgew.) O.E. Schulz	Brassicaceae	0.00	1.39	13.89	5.09
10.	*Arisaema jacquemontii* Blume	Araceae	0.00	0.00	9.72	3.24
11.	*Artemisia* sp. 1	Asteraceae	16.67	0.00	1.39	6.02
12.	*Artemisia* sp. 2	Asteraceae	0.00	4.17	19.44	7.87
13.	*Artemisia subdigitata* Mattf.	Asteraceae	0.00	12.50	5.56	6.02
14.	*Asparagus filicinus* Buch.-Ham. ex D.Don	Asparagaceae	9.72	0.00	0.00	3.24
15.	*Aster himalaicus* C.B. Clarke	Asteraceae	11.11	25.00	1.39	12.50
16.	*Aster albescens* (DC.) Hand.- Mazz	Asteraceae	20.83	26.39	16.67	21.30
17.	*Astragalus multiceps* Wall. ex Benth.	Fabaceae	1.39	9.72	11.11	7.41
18.	*Astragalus candolleanus* Royle ex Benth.	Fabaceae	0.00	12.50	19.44	10.65
19.	*Berberis aristata DC.*	Berberidaceae	38.89	38.89	37.50	38.43
20.	*Betula utilis* D.Don	Betulaceae	0.00	0.00	4.17	1.39
21.	*Bistorta macrophylla* (D. Don) Sojak	Polygonaceae	0.00	33.33	1.39	11.57
22.	*Bistorta affinis* (D. Don) Greene	Polygonaceae	8.33	0.00	11.11	6.48
23.	*Carex* sp. 1	Cyperaceae	65.28	18.06	29.17	37.50
24.	*Carex* sp. 2	Cyperaceae	56.94	16.67	29.17	34.26
25.	*Carex* sp. 3	Cyperaceae	27.78	18.06	37.50	27.78
26.	*Chesneya nubigena* (D.Don) Ali	Fabaceae	0.00	0.00	4.17	1.39
27.	*Cremanthodium ellisii* (Hook.f.) Kitam.ex Kitam.& Gould	Asteraceae	0.00	0.00	5.56	1.85
28.	*Cicerbita macrorhiza* var. *saxatilis* (Edgew.) P.Brauv	Asteraceae	0.00	2.78	15.28	6.02
29.	*Clematis buchananiana DC.*	Ranunculaceae	6.94	0.00	0.00	2.31
30.	*Coelogyne sp.*	Orchidaceae	4.17	0.00	0.00	1.39
31.	*Conyza sp.*	Asteraceae	0.00	4.17	38.89	14.35
32.	*Cortia depressa* (D.Don) C.Norman	Apiaceae	0.00	0.00	20.83	6.94
33.	*Corydalis juncea* Wall.	Fumariaceae	5.56	16.67	22.22	14.81
34.	*Cotoneaster microphyllus* Wall. ex. Lindl.	Rosaceae	27.78	52.78	19.44	33.33
35.	*Cotoneaster affinis* Lindl.	Rosaceae	0.00	6.94	0.00	2.31
36.	*Cyananthus microphyllus* Edgew.	Campanulaceae	0.00	0.00	2.78	0.93
37.	*Delphinium brunonianum* Royle	Ranunculaceae	0.00	15.28	37.50	17.59
38.	*Ephedra gerardiana* Wall.ex Stapf	Ephedraceae	0.00	0.00	27.78	9.26
39.	*Equisetum sp.*	Equisetaceae	11.11	0.00	0.00	3.70
40.	*Euphorbia himalayensis* Klotzsch	Euphorbiacea	0.00	5.56	6.94	4.17
41.	*Euphorbia stracheyi* Boiss.	Euphorbiacea	0.00	0.00	11.11	3.70
42.	*Fragaria nubicola* Lindl. Ex Lacaita	Rosaceae	0.00	2.78	11.11	4.63
43.	*Galium aparine L.*	Rubiaceae	0.00	0.00	2.78	0.93
44.	*Gentiana robusta* King ex. Hook.	Gentianaceae	0.00	0.00	29.17	9.72
45.	*Gentiana depressa* D.Don	Gentianaceae	0.00	15.28	9.72	8.33
46.	*Gentianella pedunculata* (D.Don) H.Smith	Gentianaceae	0.00	2.78	27.78	10.19

S.N.	Plant species	Family	Frequency of occurrence (%) in different elevation bands			
			Lower-elevation band	Mid-elevation band	Higher-elevation band	Overall
47.	*Gentianella paludosa* (Hook.) H. Sm.	Gentianaceae	0.00	5.56	6.94	4.17
48.	*Kobresia gammiei* C.B. Clarke	Cyperaceae	0.00	13.89	31.94	15.28
49.	*Heracleum obtusifolium* Wall. ex. DC.	Umbeliferae	5.56	0.00	4.17	3.24
50.	*Hippophae tibetana* Schlecht.	Elaeagnaceae	0.00	5.56	0.00	1.85
51.	*Iris kemaonensis* Wallich ex. Royle	Iridaceae	0.00	0.00	12.50	4.17
52.	*Juniperus squamata* Buch-Ham ex. D.Don	Cupressaceae	22.22	40.28	66.67	43.06
53.	*Juniperus communis* L.	Cupressaceae	23.61	29.17	0.00	17.59
54.	*Salix calyculata* Hook.f. ex Andersson	Salicaceae	1.39	0.00	0.00	0.46
55.	*Leontopodium stracheyi* (Hook.f.) C.B. Clarke ex Hemsl.	Asteraceae	16.67	20.83	23.61	20.37
56.	*Ligustrum confusum* Decne.	Oleaceae	0.00	0.00	8.33	2.78
57.	*Lonicera hypoleuca* Decne.	Caprifoliaceae	0.00	5.56	58.33	21.30
58.	*Lonicera minutifolia* Kitam.	Caprifoliaceae	0.00	0.00	19.44	6.48
59.	*Morina nepalensis* D.Don	Morinaceae	20.83	0.00	0.00	6.94
60.	*Oxytropis williamsii* Vass.	Fabaceae	8.33	0.00	0.00	2.78
61.	*Pedicularis pectinata* Wall. Ex. Benth.	Scrophulariaceae	0.00	0.00	19.44	6.48
62.	*Pedicularis rhinanthoides* Schrenk.	Scrophulariaceae	11.11	0.00	0.00	3.70
63.	*Pedicularis flexuosa* Hook. f.	Scrophulariaceae	0.00	13.89	25.00	12.96
64.	*Pinus wallichiana* A.B. Jackson	Pinaceae	11.11	0.00	0.00	3.70
65.	*Pleurospermum apiolens* C.B. Clarke	Apiaceae	2.78	15.28	22.22	13.43
66.	*Polygonatum hookeri* Baker	Convallariaceae	0.00	8.33	23.61	10.65
67.	*Polygonatum cirrhifolium* (Wall.) Royle	Convallariaceae	0.00	5.56	13.89	6.48
68.	*Potentilla fructicosa* Lindl. ex Lehm.	Rosaceae	19.44	34.72	15.28	23.15
69.	*Potentilla peduncularis* D.Don	Rosaceae	0.00	6.94	41.67	16.20
70.	*Primula primulina* (Spreng.) H. Hara	Primulaceae	0.00	18.06	15.28	11.11
71.	*Rhododendron anthopogon* D.Don	Ericaeae	31.94	19.44	0.00	17.13
72.	*Rhododendron lepidotum* Wall. ex D. Don	Ericaeae	0.00	11.11	41.67	17.59
73.	*Rosa sericea* Lindl.	Rosaceae	41.67	63.89	18.06	41.20
74.	*Rumex nepalensis* Spreng.	Polygonaceae	0.00	0.00	22.22	7.41
75.	*Saussurea nepalensis* Spreng.	Asteraceae	0.00	5.56	15.28	6.94
76.	*Saxifraga andersonii* Engl.	Saxifragaceae	0.00	9.72	2.78	4.17
77.	*Spiraea canescens* D.Don	Rosaceae	0.00	0.00	38.89	12.96
78.	*Swertia cuneata* D.Don	Gentianaceae	0.00	0.00	27.78	9.26
79.	*Swertia chirayita* Karsten	Gentianaceae	0.00	0.00	23.61	7.87
80.	*Tanacetum dolichophyllum* Kitam.	Asteraceae	41.67	47.22	73.61	54.17
81.	*Taraxacum eriopodum* DC.	Asteraceae	1.39	4.17	0.00	1.85
82.	*Tanacetum sp.* (local name Khamsang)	Asteraceae	11.11	25.00	65.28	33.80
83.	*Thalictrum cultratum* Wall.	Ranunculaceae	0.00	1.39	27.78	9.72
84.	*Thalictrum alpinum* L.	Ranunculaceae	11.11	22.22	0.00	11.11
85.	*Thymas linearis* Benth.	Lamiaceae	0.00	0.00	12.50	4.17
86.	*Trifolium sp.*	Fabaceae	0.00	5.56	12.50	6.02
87.	*Verbascum thapsus* L.	Scrophulariaceae	4.17	12.50	8.33	8.33
88.	*Viola biflora* L.	Violaceae	0.00	0.00	6.94	2.31

Table 5: Families with number of genera and species recorded from the study area

S.N.	Families	No. of Genera	No. of species
1	Asteraceae	10	16
2	Rosaceae	5	7
3	Gentianaceae	3	6
4	Ranunculaceae	4	5
5	Fabaceae	4	5
6	Scrophulariaceae	2	4
7	Cyperaceae	2	4
8	Primulaceae	2	3
9	Polygonaceae	2	3
10	Cupressaceae	1	3
11	Apiaceae and Lamiaceae	Two each (4)	One each (4)
12	Caprifoliaceae, Convallariaceae, Ericaeae and Euphorbiaceae	One each (4)	Two each (8)
13	Alliaceae, Araceae, Asparagaceae, Berberidaceae, Betulaceae, Brassicaceae, Campanulaceae, Elaeagnaceae, Ephedraceae, Equisetaceae, Fumariaceae, Iridaceae, Morinaceae, Oleaceae, Orchidaceae, Pinaceae, Rubiaceae, Salicaceae, Saxifragaceae, Umbeliferae and Violaceae	21(One each)	21(One each)
Total	37 Families	64 Genera	89 Species