Does scientific forest management promote plant species diversity and regeneration in Sal (*Shorea robusta*) forest? A case study from Lumbini collaborative forest, Rupandehi, Nepal

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Scientific forest management is an emerging need for managing existing natural forests of Nepal on the basis of silvicultural intervention. The study was carried out in Lumbini Collaborative Forest at Rupandehi District of Nepal, where Sal (*Shorea robusta*) forests are being managed under Irregular Shelterwood System with eighty years of cutting cycle since 2011–2012. The study was purposed to find out the intial effects of silvicultural intervention on plant species diversity and regeneration of Sal forest. The vegetative sampling was done using quadrate method based on the principle of simple random sampling both in the managed as well as the unmanaged parts of forest. The study found out remarkable increase in regeneration as well as decrease in plant diversity in the managed first and second-year stands (Block I and Block II respectively) as compared to the unmanaged stand (Block III) at its initial level of implementation. The mean value of diversity, richness, evenness, dominance index and regeneration of *S. robusta* varied significantly ($p \leq 0.05$) between the managed blocks (stands). The seedling density of *S. robusta* was found higher in the managed blocks (Block I and Block II) as compared to the unmanaged one (Block III) in terms of height class. The study recommends implementation of Irregular Shelterwood System for managing the existing degraded Sal forests of the Terai region of Nepal, however, its long term effects on plant species diversity should be further studied in detail.

Key words: Silvicultural intervention, regeneration, plant diversity, irregular shelterwood system

The regeneration status of a forest indicates its health and vitality while healthy forest ensures good future regeneration. The regenerating and productive character of forest is determined by presence of different age-group of seedling, sapling and tree (Chauhan *et al.*, 2008). Moreover, regeneration of Sal (*Shorea robusta* Gaertn. F., family Dipterocarpaceae) is a complex and baffling problem (Bisht, 1989). Regeneration is measured to determine whether it meets the objective of sustainable forest management, and in particular, whether the productive capacity and biological diversity of forest are maintained (Lutze *et al.*, 2004).

Scientific forest management aims to regulate the sustained yield by improving the degrading nature of a forest on the one hand and ensures its regeneration through replacement of old stocks by new ones in future. Scientific forest management follows appropriate silvicultural system while tree felling and regeneration activities are integral part of it. To be silviculturally sustainable, forest management must ensure good regeneration, maintain proper age class (age-gradation), normal increment and normal growing stock (Subedi, 2011). Various efforts have been made on developing suitable silvicultural systems while mostly in building judicious canopy opening for regeneration of Sal (Troup, 1986).

Information on the implication of different types of silvicultural system or forest management on regeneration and tree diversity could be significant to predict future trends in species composition and stand structure in order to optimize the possible forest management strategies. In Nepal, such information is very scanty. However, the

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regeneration status of Sal forest in Nepal has been assessed in the Terai region. In this regard, this study is expected to generate necessary data for active forest management at micro level. The study was focused on rigorous comparison of scientific management of Sal forest in the terai region of Nepal through silvicultural intervention on the vegetation attributes with its traditional management, where scientific forest management has been a wide demand for a long time. This may help to understand the differences or similarities in stand structure, diversity and species composition, which will justify the need of preparing scientific forest management plans in future.

Materials and methods

Study site

The study was conducted in the Lumbini Collaborative Forest which is located in Saljhandi and Rudrapur Village Development Committees (VDCs) of Rupandehi district of Western Nepal (Figure 1). The study area occupies an area of 1321 ha, and is located between 27º40'32" N to 27º45'13" N latitudes and 83º12'55" E to 83º14'24" E longitudes. The elevation of the study area ranges from 100 m to 1,229 m above mean sea level. People living in the 16 VDCs, from Saljhandi in the north to Aama in the south, are the users of this collaborative forest (LCFMG, 2014).

The forest has been managed under Irregular Shelterwood System which is a compromise between shelterwood group system and group selection system (Parkash and Khanna, 1979). Simply, the trees of exploitable diameter are removed leaving behind the mother trees for seeds; the mother trees will be removed after regeneration is established. Regeneration felling is in the pattern of group system, but as the regeneration period is long, the crop produced is uneven-aged or irregular. Weeding, cleaning, thinning, pruning, girdling, climber or bush cutting and artificial planting are carried out as per the need. The whole forest has been divided into eight periodic blocks for the purpose of the management of Sal forest under 10-year regeneration period and 80-year rotation period. Area control method of yield regulation has been adopted; so, each periodic block has been sub-divided into 10 annual sub-blocks (ASB) where regeneration felling activities will be carried out each year (LCFMG, 2014).

The study was conducted in the Periodic Block (PB) I where regeneration felling operation was carried out in its two annual sub-blocks- ASB1 and ASB3 in 2012/13 and 2013/14, respectively while eight sub-blocks would be successively managed in the coming years as per the management plan. For the study purpose, the two annual sub-blocks were studied as managed blocks *viz*. Block I (ASB 1, first-year stand)

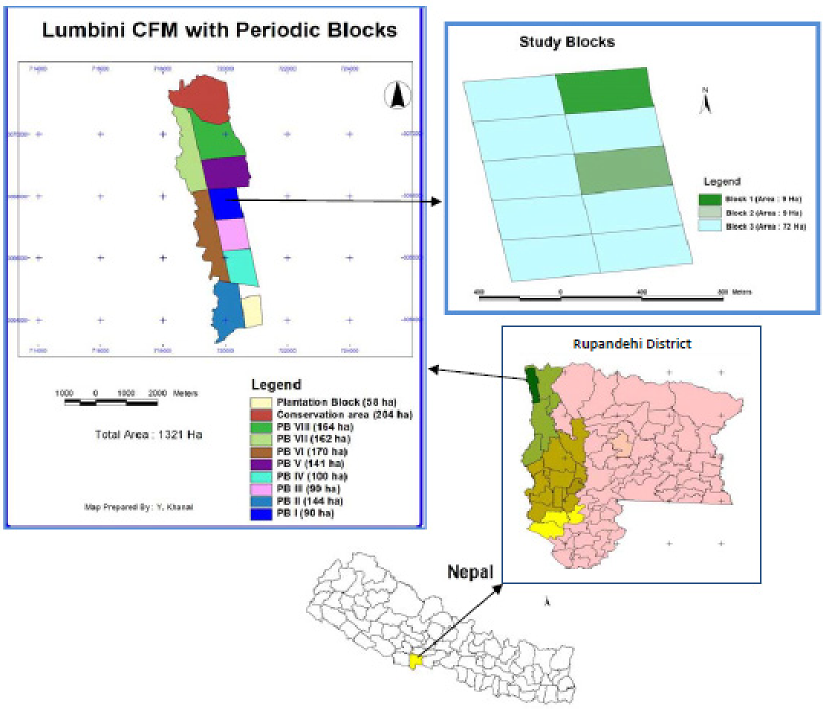

Fig. 1: Map of the study area

and Block II (ASB 3, second-year stand) while the other sub-blocks within the Periodic Block I were studied as unmanaged block (controlled/no regeneration felling) i.e. Block III to analyze the effect of silviculture intervention in the forest. The areas of Block I and Block II were 9 ha each whereas the area of Block III (with 8 annual sub-blocks) was 72 ha (LCFMG, 2014). Block I was managed under regeneration felling with post-harvesting operation while Block II under regeneration felling only with no post harvesting operation till our field study in 2014. The whole area of PB I was fenced to minimize the effect of grazing and human disturbance. Similarly, PB I was divided into two 45 ha parts with 3 m wide inspection path from the centre, and the whole PB was surrounded by 5 m-wide fireline for fire protection (LCFMG, 2014).

Sampling method

The data were collected in the year 2014-15. Individual plants were categorized into seedling (ht < 1.3 m), saplings (dbh < 10 cm and ht > 1.3 m) and trees (dbh > 10 cm). Vegetation sampling was based on Quadrate Method (Mishra, 1968). The quadrants of 10 m × 10 m were laid out in the study area for trees based on the principle of simple random sampling with the help of ArcGIS 10, and each quadrate was divided into four equal sub-quadrates, each 5 m × 5 m in size, from the centre and two opposite sub-quadrates were used for studying saplings and seedlings, as determined by the Species Area Curve Method (Mishra, 1968). The heights and dbh of all the trees and saplings were measured using Abney's Level and Diameter Tape (for trees) or Vernier Caliper (for saplings) in each sampling unit. Similarly, the heights of seedlings were measured. Altogether, 40 quadrates for trees and 80 sub-quadrates for regeneration in the unmanaged block while 9 quadrates for trees and 18 sub-quadrates for regeneration in each managed block were studied with 0.55% and 1.00% sampling intensities respectively.

Data analysis

The plant community composition both in the managed and unmanaged blocks were studied, and density, basal areas, frequency were calculated for each species to determine the Importance Value Index (IVI), adopted by Mueller–Dombois and Ellenberg (1974). Plant diversity was studied using Shannon Wiener's Index, Simpson's Dominance Index, Margalef's Species Richness Index, Equitability or Evenness Index and Jacard's Similarity Index which excludes herbs or climber layers. Both descriptive and inferential statistics were used for data analysis. The mean values of all the indices mentioned and the plant densities among the three blocks were studied using one way ANOVA and LSD Test.

Importance Value Index, IVI = Relative Frequency + Relative Basal Area + Relative Density

Shannon Wiener's Index, $\mathbf{H'} = -\sum_{i=1}^{s}(\mathrm{pi})(\ln \mathrm{pi})$

Simpson's Index of Dominance, C = $\sum_{i=1}^{s}(\mathrm{Pi})^2$

Margalef's Species Richness Index, d = $\frac{(s-1)}{\ln N}$

Equitability or Evenness Index, e = $\frac{H'}{\ln S}$

Jacard's Similarity Index, JI = $\frac{c}{a+b+c}$,

where, s = number of species, N = total number of individuals of species and pi = proportion of all individuals that are of species 'i'

The ratio of abundance to frequency distribution was considered regular, if < 0.025, random, if it is within 0.025 – 0.05 and contiguous, if > 0.05 (Whitford, 1949).

Results and discussion

Plant species composition and distribution pattern

The total number of plants recorded in Block I and Block II (both managed) were 14 and 23 respectively while it was 29 in Block III (unmanaged). Based on the calculation, *S. robusta* was found to be the dominant species with highest IVI of 180.09, 124.08 and 133.73 in Block I, Block II and Block III respectively (Figure 2). Similarly, *Terminalia tomentosa* was found to be the co-dominant species in the managed area (Block I and Block II) (Figure 2 and Figure 3) while *Mallotus philippensis* was found to be co-dominant species in the unmanaged area (Block III) (Figure 4). The Terai Forest Inventory carried out by the DFRS (2014) found *S. robusta* as prominent species followed by *T. tomentosa*. Similar results were noticed in the case of managed blocks (Block I and Block II) in this study too.

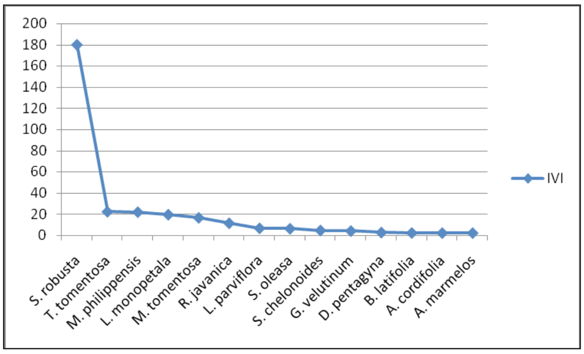

Fig. 2: Dominance diversity curve in the managed Block I

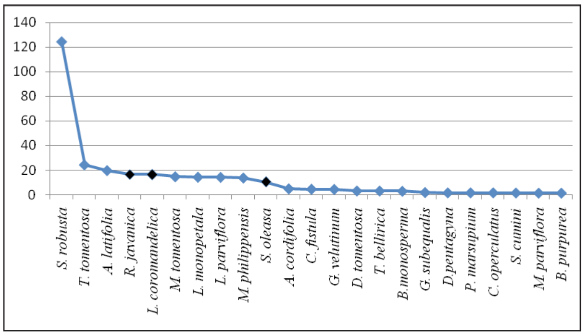

Fig. 3: Dominance diversity curve in the managed Block II

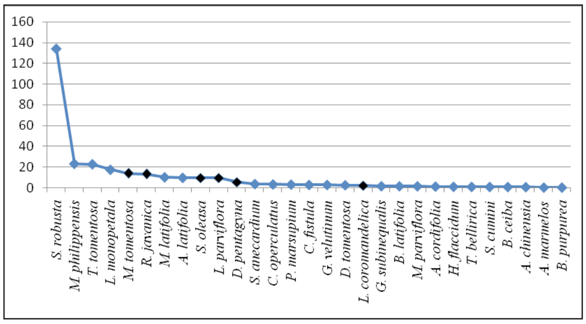

Fig. 4: Dominance diversity curve in the unmanaged Block III

Note: Grey and dark black dots represent contagious and randomly distributed species respectively.

All plant species recorded in the managed Block I were found to be contagiously distributed while few species in the managed Block II and unmanaged Block III were found to be randomly distributed. The ratio of abundance to frequency of tree species greater than 0.05 showed clumped (contagious) pattern of species distribution which reveals that most seedlings were adapted to grow closer to the mother plants, observed in all the species within the managed Block I. Similar results were depicted by Ndah *et al.* (2013) in the disturbed rainforest of Cameroon. Odum (1971) has emphasized contagious distribution pattern as the most common patterns in nature.

Plant species diversity

Species diversity refers to the frequency and variety of species within a geographical area (HMGN/MFSC, 2002). It refers to the species richness and evenness within an area which describes the structure of plant community. Plant species are directly affected by the harvesting or management practices operated in a stand.

The study showed low mean Shannon Weiner's Diversity Index in the managed block as compared to the unmanaged block of forest, affecting both species richness and evenness indices. Species diversity and concentration of dominance are generally inversed in relation. Thus, concentration of dominance of managed blocks (Block I and Block II) was found to be higher as compared to the unmanaged block (Block III) due to lower diversity within the species, and revealed *S. robusta* to be the dominated species in the managed stands. The mean value of Shannon Weiner's Index, Simpson's Concentration of Dominance and Margalef's Species Richness Index varied significantly between Block I and Block II as well as between Block I and Block III. Similarly, the mean value of Evenness Index was found to be significantly different between block I and Block III at 0.05 level of significance. This shows low diverse in tree species in managed stands as compared to unmanaged or natural stands as a result of initial effect of intervention. Sapkota *et al.* (2010) found decline in the tree diversity while dominance of *S. robusta* increases linearly along the disturbance gradient in Nepalese Sal forest, similar to our study (Table 1). Smith *et al.* (2005) compared changes in diversity under different management regime over 35 years in the sub-tropical rainforest of Australia, and found that species richness in natural condition varied slightly over this period, and also found that the richness per plot in the logged area generally declined after intervention and then gradually increased to greater extent as compared to the original diversity.

Diversity measures of understory were significantly higher in the logged forest than in the unlogged forest after it was performed for 10 years in beech forests of Shafarood in Guilan (Pourbabaei and Ranjaver 2008). Similarly,

Table 1: Mean and standard errors of plant species diversity, and evenness and richness indices

Block	No. of plot	H'	C	E	S
Block I (managed)	9	1.05 ± 0.05	0.52 ± 0.02	0.59 ± 0.02	1.14 ± 0.13
Block II (managed)	9	1.44 ± 0.06	0.39 ± 0.07	0.64 ± 0.02	1.88 ± 0.11
Block III (unmanaged)	40	1.49 ± 0.04	0.35 ± 0.09	0.67 ± 0.01	1.97 ± 0.07

Note: H' : Shannon Wiener's Index; C : Simpson's Dominance Index/Concentration of Dominance; E : Evenness Index and S : Species Richness Index.

Mohammadi *et al.* (2008) observed low value of Shannon Weiner's Index (tree species diversity) in the natural stand as compared to the managed stand with Shelterwood system in Loveh forest of Iran. Since Block I was managed with regeneration felling followed by post-harvest performed in the first and second successive years as compared to Block II where management was carried out with only regeneration felling during our study period, the mean Shannon Wiener's Index was found to be higher (1.44± 0.06) in Block II than in Block I (1.05 ± 0.05), quite similar to the unmanaged area (Block III with the mean Shannon Wiener's Index: 1.49 ± 0.04) of the forest (Table 1). In addition, Halpern and Spies (1995) found other management activities (fertilization, herbicide application, grazing) could affect upon the species composition of vegetation in addition to the initial effect of logging and site preparation.

Forest structure and diversity varied with different silvicultural treatments applied on it. Battles *et al.* (2001) found total species richness higher in plantation and shelterwood regime than in single tree and reserves stands while diversity varied from year to year under group selection system. As disturbances played leading role in species diversity, Robert and Gillium (1995) argued with intermediate-disturbance hypothesis as most applicable for forest management which prevents few species from dominating resources. Species richness relies on two separate aspects of silviculture: i) canopy cover and ii) seed bed characteristics. Canopy cover is a function based on timing and amount of wood harvested while seed bed characteristics is related with post harvesting site preparation at the same time. Block I is a stand managed under both aspects of silviculture while Block II is a stand managed with no seed-bed treatment (only harvesting). In the case of temperate forest, management effect reports either no reduction, short-lived reduction or increase in species diversity following silvicultural practices (Battles *et al.*, 2001).

Jacard Similarity Index was used to find similarity and diversity of species among the region (Pourbabaei, 2004). High similarity was noticed in the species between Block II (managed) and Block III (unmanaged) in the study area (Table 2). On the other hand, high dissimilarity was detected between Block I (managed block) and Block III (unmanaged) which may occur as a result of post- harvesting of unwanted species in course of weeding and cleaning.

Table 2: Jacard's Similarity Index (in percentage)

Study area	Jacard's Index (%)
Managed Block I with managed Block II	47.82
Managed Block I with Unmanaged Block III	43.33
Managed Block II with Unmanaged Block III	73.33

Regeneration status

The study found higher seedling and sapling densities in the managed areas (Block I and Block II) which could be the result of regeneration felling as compared to that in the controlled i.e. unmanaged area (Block III) with no regeneration felling. Block I (managed) was found to have 21,022 seedlings/ha followed by Block II (managed) with 16,555 seedlings/ha while Block III (unmanaged) had the lowest 13,035 seedlings/ha (Figure 5). Suoheimo (1999) observed 50,000 – 100,000 seedlings/ha after regeneration felling of Sal forests under uniform shelterwood system. Both shoot and root development of *S. robusta* was also observed better in open space rather than under shade (Troup, 1986). However, tree density was found to be higher in the controlled area (Block III) with 552 trees/ha as compared to the managed ones (Block I with 66 trees/ha and Block II with 133 trees/ha).

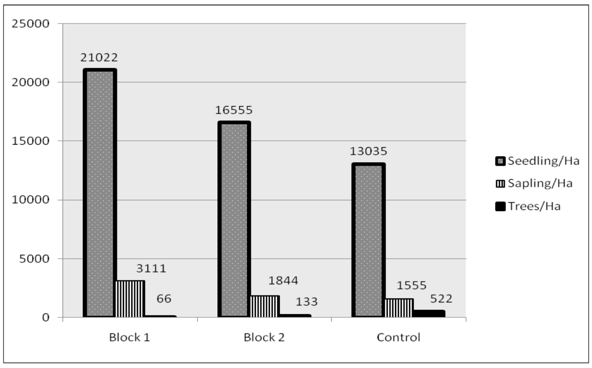

Fig. 5: Seedling, sapling and tree density in the forest

Comparison of regeneration of *S. robusta* with other species

The seedling density of *S. robusta* was found to be higher in the managed area (Block I with 13,977/ha and Block II with 9,311/ha) and low (6,445/ha) in the unmanaged area (Block III) (Fig. 6). Similarly, its sapling density was also found to be higher in the managed area (Block I with 3022/ha and Block II with 1,644/ha) and low (1,055/ha) in the unmanaged area (Block III). Compared to other species, the seedling density of *S. robusta* was found to be higher in the managed area (Block I and Block II) while it was almost similar to that of other species in the unmanaged area (Block III). The mean seedling and sapling densities of *S. robusta* per hectare varied significantly between management blocks at 0.05 level of significance, revealing significance of scientific forest management in promoting its regeneration. While the mean seedling density of other species remained insignificant between the managed blocks in response to intervention, their mean sapling density was found to be slightly higher in the controlled i.e. unmanaged area (Block III) in the study area as shown in Figure 6. In Nepal, sustainable regeneration of *S. robusta* has been reported from both the Terai (Rautiainen, 1996) and the hills (Rai *et al.*, 1999) which was not observed among natural dense forest with a high density of larger trees. Regeneration of most of the species is favored by disturbance of moderate intensity, which may be subjected to poor in low and heavily disturbed forest (Sapkota *et al.*, 2009). *S. robusta* has been facing a serious threat to its existence in the tropical and sub-tropical belts of India due to infestation by Sal borer (*Hoplocerambyx spinicornis*) and also to moisture stress caused by the combined effects of intensive grazing, repeated fire, lopping and indiscriminate harvesting (Negi *et al.*, 2002). The area of Periodic block I have been fenced supported by constructing fireline in order to minimize effects of intensive grazing, repeated fire and indiscriminate harvesting of trees. Sal is light demanding species and complete overhead light is needed in most cases from earliest stage of development (Champion and Seth, 1968). Opening of canopy in the forest stand promotes regeneration and the growth of understorey seedlings and saplings (Troup, 1986). Hence, the regeneration of *S. robusta* in the study site was found higher in the managed area (block I & II) of forest.

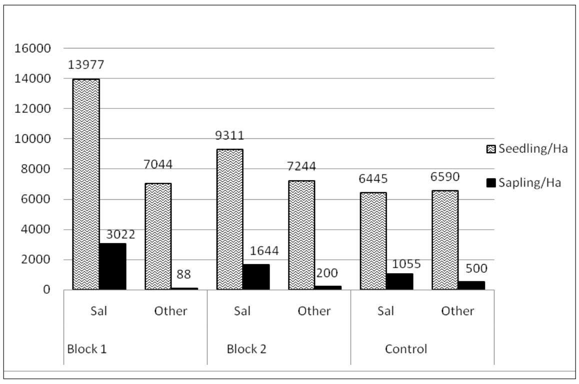

Fig. 6: Regeneration status of *S. robusta* in contrast to other species

Per hectare seedling density of *Shorea robusta* with different height classes

The density distribution of *S. robusta* seedlings in Block I, Block II and Block III were constructed based on height measurement. Height was classified into interval of 15 cm. The mean heights of *S. robusta* seedlings in Block I, Block II and Block III were approximately 73 cm, 71 cm and 65 cm respectively. The highest seedling density was noticed in the height class of 85–99cm in Block I (managed) (Figure 7). Besides, the highest seedling densities were also noticed in the height class of 70–84 cm in Block II (managed) and in the height class of 40–54 cm in the unmanaged area (block III). At each height class, the seedlings density was found to be higher in Block I (managed) followed by Block II (managed) and Block III (unmanaged), indicating effects of intervention on growth performance of the seedlings. Khan *et al.* (1986) found survival and better growth of *S. robusta* seedlings in the forest periphery compared to those under dense canopy, which illustrates the better growth and regeneration in presence of canopy opening or threshold light intensity for the process of photosynthesis in seedlings. The figures indicated decreased in density of the existing seedlings of *S. robusta* beyond 40–54 cm height class successively, which in turn signifies the problem in growth of *S. robusta* seedlings in the unmanaged area.

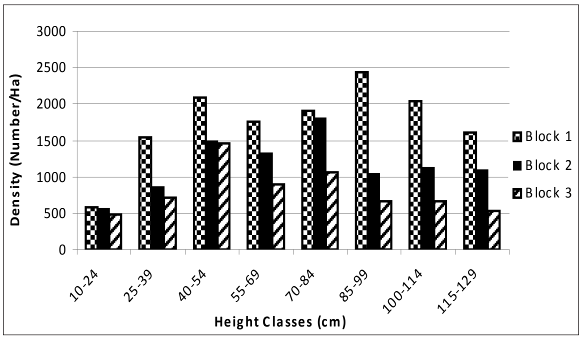

Fig. 7: Density of seedlings of *S. robusta* with different height classes

Survivorship and mortality curve of *S. robusta* in the unmanaged area

The survivorship and mortality curve of *S. robusta* was prepared on the basis of Static Life Table in accordance with the method described by Qiaoying *et al.* (2008). Static Life Table has been suggested as one of the silvicultural tools in listing distribution of all individuals in a population by age-class or other form of development. In this case, size classes were used as the surrogates of the age-classes.

The curve showed mortality of *S. robusta* seedlings as 83.6% (Figure 8) which became peak during their population development in their life period. Only 16.4% of the seedlings were found to have developed into sapling stage which is indicated by highest density of seedlings rather than saplings. This reveals the need of management for the promotion of regeneration in the study area. Since *S. robusta* requires over-head light for their growth, the canopy should be opened for their survival. Trees of dbh class 30–40 cm exhibited highest life expectancy population structure of *S. robusta* from seedlings to matured stage, which indicated that the regeneration of *S. robusta* had been hampered due to various biotic and abiotic factors although the trees were found to have produced abundant number of viable seeds. The mortality of Abies georgei on the north facing slope of SW China was 88% (Qiaoying *et al.*, 2008), higher than the one found in this study. A wide range of biotic and abiotic factors are responsible for large scale death of seedlings and saplings of *S. robusta* leading to its poor regeneration. Since, the area under PB I was fenced i.e. protected against biotic factors, it can be assured that abiotic factor was dominant in growth of seedlings in the unmanaged area of the forest, and so, further detailed study is needed to come into conclusion.

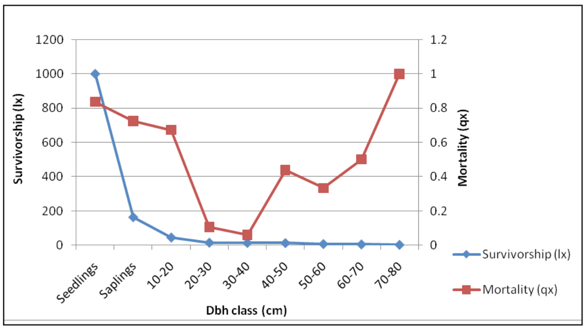

Fig. 8: Survivorship and mortality curve of *S. robusta*

i) Change in proportion (×1000) of individual surviving (lx) with different dbh classes of *S. robusta*

ii) Mortality (qx) curve with different dbh classes of *S. robusta.*

Conclusion

Foresters have been facing challenges in developing effective management strategies in conserving regional biodiversity, sustaining the forest resources and meeting the ever increasing demand for wood and wood products, especially in the developing countries. They need to design suitable management options for protection as well as production of their forest resources. For this, maintaining regeneration of many valuable tree species has become a difficult task now. In this regard, an irregular shelterwood system, a strategy adopted in the Terai region of Nepal, could be an alternative for promoting regeneration of *S. robusta*, a valuable tree species in the world. Besides the density of seedlings and saplings, the growth performance of the seedlings of *S. robusta* and its dominance has been found to be remarkable in the managed areas than in the natural stands. The distribution pattern of this species in the managed areas was found to be moreover contagious, exhibiting the clumped pattern of their growing. According to Smith *et al.* (2005), the regeneration felling followed by post harvesting decreases species diversity in the managed stands as management is based on irregular shelterwood system at its initial stage, which will increase in the long run than in the natural stands. Various studies recommend removal of moderate number of trees for maintaining tree diversity and regeneration in long run (Smith *et al.*, 2005; Sapkota *et al.*, 2009). Hence, this study recommends implementation of irregular shelterwood system for managing existing degraded Sal forest, while its long-term effects on plant species diversity should be further studied.

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Annex I

List of plant species in the study area

S.N.	Scientific Name	Family	Managed Block I	Managed Block II	Unmanaged Block III
1.	*Shorea robusta*	Dipterocarpaceae	+	+	+
2.	*Terminalia tomentosa*	Combretaceae	+	+	+
3.	*Litsea monopetala*	Lauraceae	+	+	+
4.	*Adina cordifolia*	Rubiaceae	+	+	+
5.	*Glochidiom velutinum*	Euphorbiaceae	+	+	+
6.	*Mallotus philippensis*	Euphorbiaceae	+	+	+
7.	*Aegle marmelos*	Rutaceae	+	-	+
8.	*Rhus javanica*	Anacardiaceae	+	+	+
9.	*Lagerstroemia parviflora*	Lythraceae	+	+	+
10.	*Mitragyna parviflora*	Rubiaceae	-	+	+
11.	*Anogeissus latifolia*	Combretaceae	-	+	+
12.	*Grewia subinaequalis*	Malvaceae	-	+	+
13.	*Schleichera oleasa*	Sapindaceae	+	+	+
14.	*Lannea coromandelica*	Anacardiaceae	-	+	+
15.	*Terminalia bellirica*	Combretaceae	-	+	+
16.	*Cassia fistula*	Fabaceae	-	+	+
17.	*Diospyros tomentosa*	Ebenaceae	-	+	+
18.	*Dillenia pentagyna*	Dilleniaceae	+	+	+
19.	*Syzygium cumini*	Myrtaceae	-	+	+
20.	*Cleistocalyx operculatus*	Myrtaceae	-	+	+
21.	*Pterocarpus marsupium*	Fabaceae	-	+	+
22.	*Stereospermum chelonoides*	Bignoniaceae	+	-	-
23.	*Buchanania latifolia*	Anacardiaceae	+	-	+
24.	*Semecarpus anacardium*	Anacardiaceae	-	-	+
25.	*Madhuca latifolia*	Sapotaceae	-	-	+
26.	*Bombax ceiba*	Bombacaceae	-	-	+
27.	*Miliusa tomentosa*	Annonaceae	+	+	+
28.	*Hymenodictyon flaccidum*	Rubiaceae	-	-	+
29.	*Anthocephalus chinensis*	Rubiaceae	-	-	+
30.	*Butea monosperma*	Leguminosae	-	+	-
31.	*Bauhinia purpurea*	Leguminosae	-	+	+