Effect of management practice and age on increment in *Pinus patula* plantations in Nepal

S. P. Dangal[1] and A. K. Das[2]

With the large-scale plantation commenced in the early 1980s, nearly 370,000 hectares of plantations have been successfully established in Nepal. More than 26 thousand hectares (ha) of plantations have been established since late seventies in Sindhupalchok and Kavrepalanchok districts and are handed over to communities as community forests. *Pinus roxburghii* and *Pinus patula* are the dominant species of these plantations aiming to maximize biomass productions and restore greenery in degraded hills. The growth rate *Pinus patula* was estimated 15 m³ ha^{-1} yr^{-1} in 1995 which but reduced to 7 m³ ha^{-1} yr^{-1} in 2011. As *P. patula* is an exotic species to Nepal, knowledge on effect of age and management practices on increment was limited in Nepal as well as in the regions. This is hindering in implementations of appropriate silviculture by the forest managers. To fill this knowledge gap, primary data were collected taking sample cores from 120 trees in 2015 from four community forests of Chaubas ridge of Kavrepalanchok district for dendrochronological assessment. Among these four community forests, two followed improved management practices and two followed conventional management practices. To substantiate the data, secondary data of similar studies were used. Dendrochronological assessment taking sample cores of 120 and 80 were conducted in 2000 and 2005 respectively in plantations,managed by community forest users groups, carried out between 1975 AD and 1990 AD in Chaubas ridge of Kavrepalanchok districts. The study found that the growth rate decreased after 12 years and this rate was bigger in the higher density class. The cumulative increment was higher in the lower density class but was found to have retarded rapidly after 15–17 years of age in the higher density class as well as in the conventionally managed plantations. The study recommends conducting planned thinning from the early age of 10–12 years while the final felling is recommended to be executed at the age of 30±5 years for *P. patula* to maximize volume production. However, most of the plantations have crossed its rotation age, growth rate has been stagnated and there is slim scope of increment from further thinning. In such case,as natural regeneration of the same species is observed encouraging, the study suggest to keep 10–15 seed trees and harvest the remaining.

Key words: Conventional management, dendrochronological approach, density, growth rate, improved management,

Globally, plantations forest account for 264 million hectares (ha). These plantations are mostly established to fulfil two third of the round wood demand and are mostly dominated by broad leaves (40%) and conifer (31%) (FAO, 2010).With the commencement of a large-scale plantations in the early 1980s (Gilmour *et al.*, 1990), nearly 0.4 million ha plantations have been successfully established particularly in the mid hills of Nepal dominated by Pines especially *Pinus patula* (DoF-a, 2012).The main objectives of these plantations were to restore degraded land with forest cover and to fulfil the need of domestic and industrial demand of firewood and timber (Gilmour *et al.*, 1990). Though *P. patula* is an exotic species, it grows considerably faster than the indigenous pines in a very poor soil (Jackson, 1994) and has been dominating species to rehabilitate the degraded hills of Nepal. Establishment of these plantations incurred a huge cost but benefits from these plantations can be maximized only if they are managed adopting the principles of forest management (Evans, 2000) to enhance the biomass on trees

[1] PhD Candidate, Mewar University, Chittorgarh, Rajasthan India. E-mail: Shambhudangal@hotmail.com
[2] Senior Technical Advisor TGG-N Project, FECOFUN, Kathmandu, Nepal

(Silva *et al.*, 2009). However, decline in yield has been reported due to the poor application of management prescriptions (Evans, 2000). Similarly, annual increment that leads to yield is normally affected by the age of plantations and management practices. When a tree becomes older and grows bigger, stand density influences the rate of increment. Higher the crop density, more would be the competition among the trees for soil nutrients, water, light and growing space (Dwivedi, 1993). Thinning is a silviculture tool to reduce competition as tree grows with age and it results in greater availability of light, water and nutrients to the remaining trees. This contributes to accelerated diameter growth (Demers *et al.*, 2016). In Nepal, appropriate prescriptions for plantations management have been neglected as most of the plantations have been considered as means of protection (Chand *et al.*, 2006) where community forest user's remove tree based on their requirement. Conventional management is typically performed by "selective logging" extracting small number of commercial species from a large number of non-commercial species (Griscom *et al.*, 2013). Due to absent of appropriate management practice especially delayed in thinning in plantations, a huge amount of potential increment that is equivalent to US $ 176–235 ha^{-1} yr^{-1}, in pine plantations has been lost (Hunt *et al.*, 2001). The improved management technologies in the forestry sector can be adopted in optimizing the productivity (FAO, 2011) which is highly limited among the forest managers and academia in Nepal as well as in Asia. Hence, this paper is aimed to generate management options along with an analysis on how increment is affected by age and management practices.

Materials and methods

Study area

The primary data for the study was collected in 2014 from Chaubas ridge of Kavrepalanchok district (Figure 1). The Chaubas ridge was a severely degraded overgrazed barren land during late seventies. More than 400 ha of these degraded hills were rehabilitated mostly by Pine species with the technical and financial support from Australian Aid for International Development (AusAID), and the Department of Forests along with local community (Eijnatten *et al.*, 2001 & Gilmour *et al.*, 1990).

After 1997, two to three thinnings were held in some forests; those consisting *Pinus patula* species, adopting Thinning Guidelines NACRMLP, 2006 & Timilsina, 2005. Despite of these guidelines many communities are removing trees for their subsistence use in conventional way.

The study was carried out in four community forests (CFs) dominated by *P. patula* (Table 1). Two of them conducted thinning using the thinning guidelines published by Department of Forests Research and Survey 2006. The forests where thinning guidelines was followed here after referred improved management and two which had not adopted referred as conventional management practice.

All four CFs have a similar altitudinal range between 1850 and 2126 m.s.l. facing mostly South East and South-West. Loamy Clay soil mostly brown colour found without any

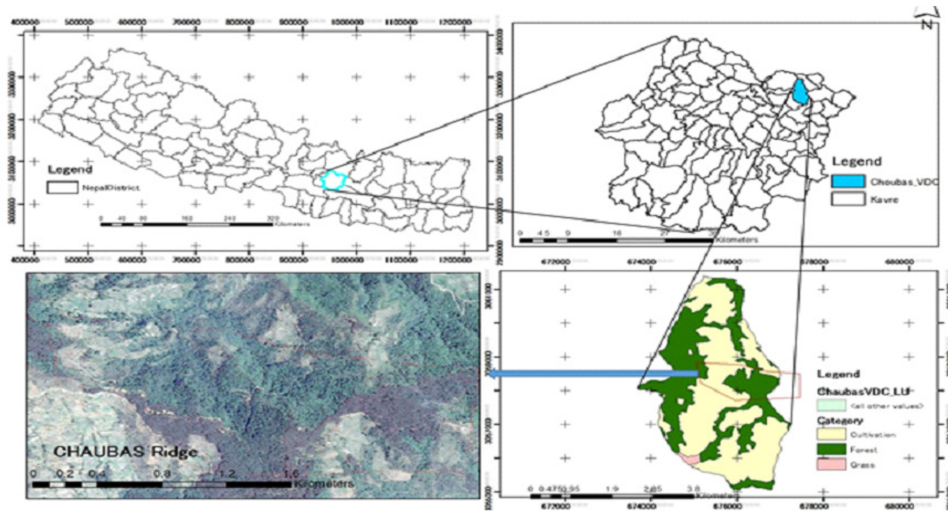

Fig. 1: Location of study area, Chaubas ridge in Kavrepalanchok district, Nepal

Table 1: Details of the study area

Age of plantations (yrs)	Improved Management			Conventional Management		
	Forest Name	# of HH	Area (ha)	Forest Name	# of HH	Area (ha)
35-40	Lankuri Rukh	80	12.0	Naya Bihani	71	16.0
30-35	Dharapani	63	35.0	Lamrang	81	19.0

indication of erosion in all the sites though these forests have slopes ranging from 8 to 25 degree. As pine needles normally do not promote regeneration of grasses, animal grazing is very low in all the areas. Based on the records from the nearby hydrological station, the annual average precipitation is 1,923 mm, which falls mainly between June and September (NEA, 2011).

Sampling and measurements

The study conducted earlier in 2001 and 2005 were not confined to these four CFs and hence they are considered for cross reference. However, similar methods of sampling and preliminary analysis of tree core were adopted. Following the techniques adopted by Hunt *et al.*, 2001 & De Bell *et al.*, 2001, diameter increment of individual trees over age and different stand densities, adopting dendrochronological approach, was measured taking core samples of individual trees.

In 2001 & 2005, a total of 120 and 80 sample plots were established in different stand densities establishing a circular plot of 100 m^2 and one dominant tree was selected from each sample plot to collect core sample (Hunt *et al.*, 2001 & Chand *et al.*,2006). Primary data was collected in 2014 taking a total of 120 tree core sample from 60 sample plots of 8.92 m radius were laid out for the purpose of forest growing stock measurement. Core samples from a dominant and a codominant trees within each plot were taken. The reason behind to consider dominant and codominat trees only was to maintain consistency on tree selection among the plots (Hunt *et al.*, 2001). The number of tree per ha around the dominant and codominant trees within the plot were observed different. Hence, to estimate more accurate stand density , trees were counted within 5.64 meter radius from the selected trees.

From each selected tree, one core sample (0.5 cm round) was collected with the help of 30 cm long HAGLOF Increment Borer (Hunt *et al.* 2001). The core samples were collected from the most cylindrical section of the stem at 20–30 cm above the ground level. Two cores were taken per tree so as to get the average if the tree bole was not cylindrical. Diameter at breast height and total height of the cored trees were again measured using diameter tape and vertex. Similar technique was followed to measure the core, stand density, height and diameter of the 6 dominant trees with height and diameter to understand the maximum growth potential under similar environment.

For the measurement of core, each core was placed in a wooden frame of half circle (half of 0.5 cm) perpendicular channel. The core was first well sanded to increase the visibility of rings and then starting from the pith, the length of each section of the core was measured in mm with the help of Vernier Calliper, and recorded in a format for analysis. Each ring denoted one year and the first ring was considered as first year growth though it takes one year to get height where core was taken.

Data analysis

Stand densities were estimated from a number of stems counted in 5.64 m^2 radius plot as used by Hunt *et al.*, 2001 & Chand *et al.*, 2006 in their studies. This increases consistency to compare result among different studies. The core measurement data were further grouped into three stand density classes *i.e.* < 300 trees ha^{-1}, 300–600 trees ha^{-1} and above 600 trees ha^{-1} hereafter referred as low, medium and high stand density, respectively. Similarly, the data were also grouped based on the management practices including improved and conventional management and normality test was carried out following the Kolmogorov-Smirnov and Shapiro-Wilk test methods (Razali *et al.*, 2011) to understand data normality so as to decide the application of tests. All the data were estimated to be normal and hence decided to use parametric tests in all cases.

To examine the effect of management practices on increment, Analysis of Covariance (ANCOVA) was used (De Bell *et al.*, 2001). The ANCOVA is the combination of Regression Analysis and ANOVA. Linear regression analysis was used to test whether there was any effect of age on diameter increment (Stock *et al.*, 2012). In addition, trend lines and equations were developed to assess the future increment trend from different angles.

Results and discussion

In overall, the current average stand density within the study sites varied regardless of management systems. The average densities estimated in forests with improved management was 436 stems ha^{-1} and forest with conventional management practice was 540 stems ha^{-1}. Findings of the study have been presented and discussed in two subheadings as below.

Management practices affecting diameter increment

To perform ANCOVA test, best fitted line was drawn using regression equation of $y = -0.00619x + 2.7753$ from measured increment data of various age. Residual/deviations were estimated from the best fitted line.. The residual estimated from deviation was used for one tail ANOVA t-tests. The test showed a significance difference in increment between improved and conventional management of *P. patula* at 95% confidence level with a Degree of Freedom 33 (since p value 0.037426826 was less than 0.5).

The study conducted in 2005 to assess the increment difference between thinned and un-thinned plantations showed a clear evident that the radial increment is 37% higher in thinned plots after the plantation crossed four years but in the both cases the increment retarded from second year as shown in figure 2 (Chand *et al.*, 2006). Similar result was obtained from the measurement conducted in 2014 in improved and conventional managed plantations. As stated earlier, removal of trees in both areas began after 11 years. However, the effect of improved practice was seen after 17 years where increment rises sharply (Fig. 3). The little effect on increment in first thinning which was conducted around 10–11 years could be due to very light mechanical thinning (10% of stems). The increment again fallen sharply after 22 years and demonstrated very little effect on increment following thinnings. This means, late thinning has less effect on increment since a stand which is un-thinned or improperly thinned can't respond the effect on a stagnated stand and similarly, thinning in a dense stand kept too long responses negative increment (Punches, 2004). The average annual increment difference was estimated to be higher (0.25 mm yr^{-1}) after the improved management systems have been adopted where 1.48 mm and 1.23 mm were measured in improved and conventional management systems, respectively.

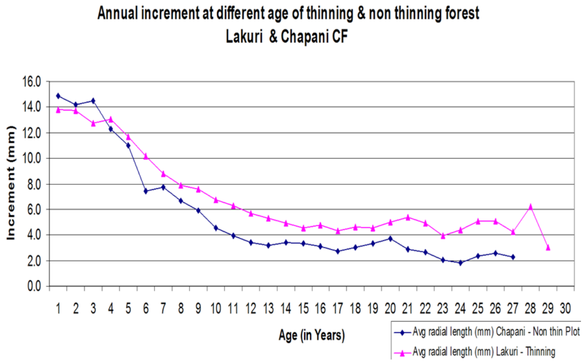

Fig. 2: Difference in annual increment by management practices (2006)

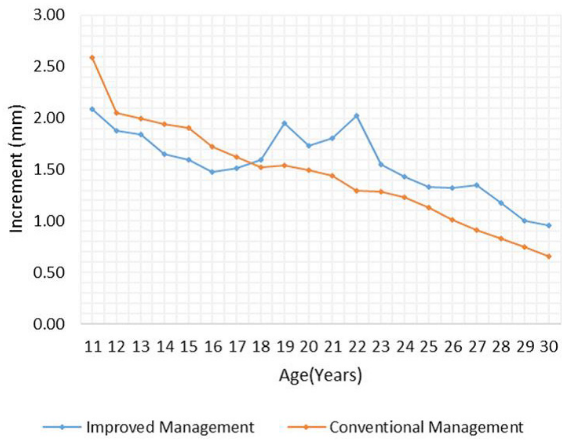

Fig. 3: Difference in annual increment by management style (2015)

These difference in increment demonstrated that improved management systems have impacts on increment as the proper thinning, as the key management tool in plantation, increase diameter growth by improving availability of light, water, and nutrient to the retained trees (Demers *et al.*, 2016). There has been significant positive effect on the cumulative increment in improved management system than in the conventional management system (Fig. 4).

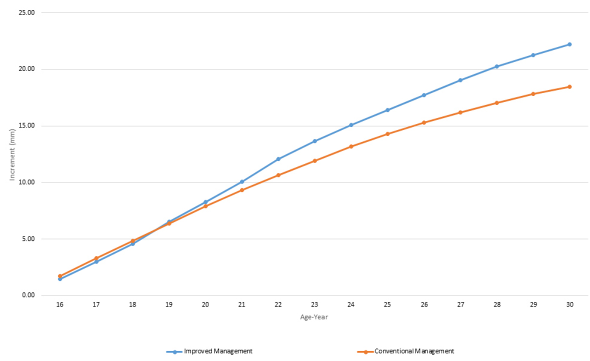

Fig. 4 : Variation in cumulative increment between improved and conventional management practices

Cumulative increment was estimated almost equal until the age of 19 years after which increment in improved management system gradually becomes higher. Both the improved and conventionally managed plantations have different tree density and effect on thinning was estimated to be different. The cumulative increments between the improved and conventionally managed plantation in various density classes showed a distinct pattern (Figures 5 and 6). The cumulative increment was distinctive after the age of 15 years in improved management where as it was not very prominent until the age of 20 years. The thinned gap between the two lines density less than 300 tree ha^{-1} and between 300 to 600 trees ha^{-1} in figure 4 showed that the response of thinning after the age of 17 years was not significant as tree response to thinning if they are thinned before 16 or 17 years of age (Demers *et al.*, 2016). This could be due to the effects of competition for light, and availability of nutrients and ground water. This clearly indicated the need for reduction of density below 600 trees ha-1 in around 15 years. Similarly, this results implicates that late and unmanaged thinning contribute less on increment as the increment normally reduces after it has reached age between 8–15 years (Gerelbaatar *et al.*, 2011).

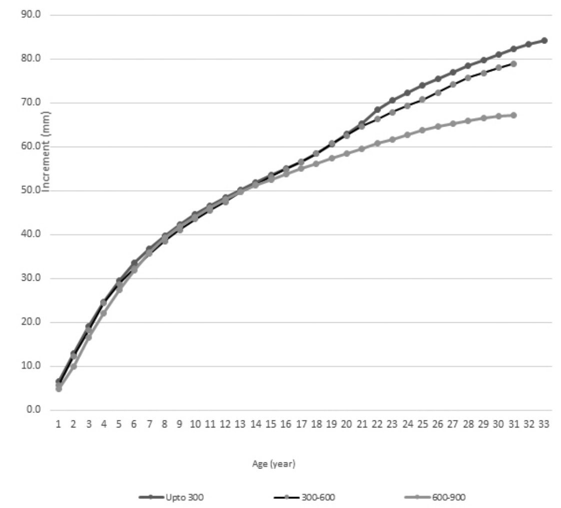

Fig. 5: Cumulative increment in improved management in different densities

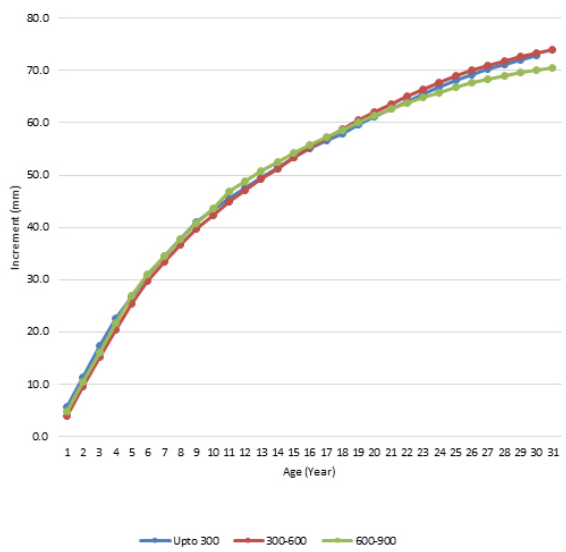

Fig. 6: Cumulative increment in conventional management in different densities

In the plantations under conventional management (Fig. 6), the cumulative increment was same up to 22 years in all the three density classes, and after then, the increment rate was low in the high-density class, but no difference was noticed in the remaining two density classes. In this case, growth might be stagnated and thinning was needed before this age (Punches, 2004).

The low stand density in conventional management practices has yielded low increment than in similar density of improved management system. This could be due to the planned way of creating space during the intervention of improved management. Normally, in a stand managed under conventional management, big trees are removed leaving the trees with inferior quality which naturally grow slower than the vigorous one. It is opposite in the case of a stand of improved management where the dead, diseased, dying, suppressed and inferior trees are removed first leaving the healthier big trees meant for natural regeneration and high return (Demers *et al.*, 2016).

The Mean Annual Increment (MAI) was found to be notable difference in the sands managed under improved and conventional management systems and were also vary with stand densities within each of the management systems (Figures 7 and 8). The reductions in the MAIs between improved and conventionally managed plantations were found to be almost similar until 12 years. The fluctuations in the MAIs in all density classes could be due to the site factors and removal of trees in conventionally managed plantations. It indicated that there was no effect of density until 12 years of age. After 12 years, the MAI in the conventionally managed plantations was found to have declined; higher decline in the MAI noticed in the high density class and almost similar decline noticed in the medium and low density classes. Similar pattern was indicated in the high density class in the improved management practices but, fluctuations (sharp increase and decrease) in the MAIs were noticed in the other two density classes.

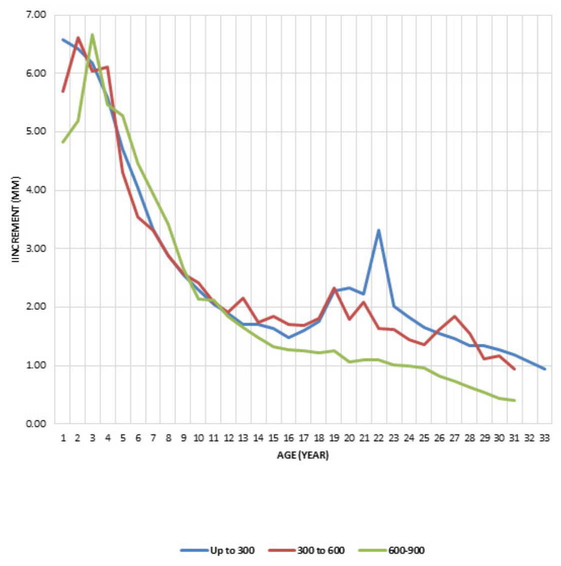

Fig. 7: Annual increment in improved management

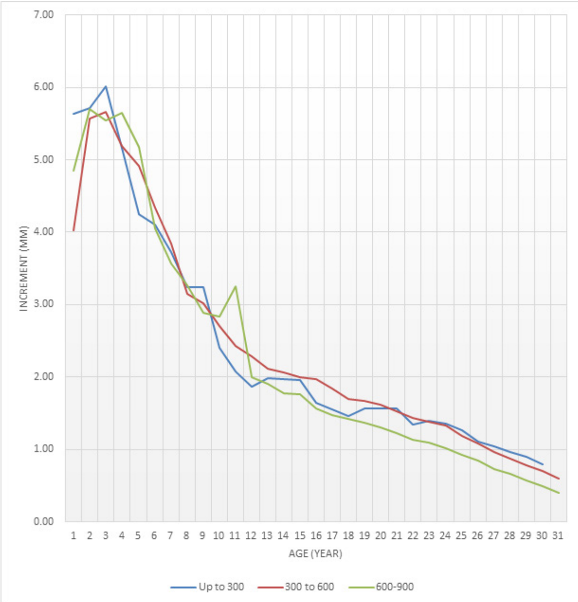

Fig. 8: Increment in conventionally managed

This could be the impact of thinning carried out relatively in planned way after the age of 12 years in the different blocks of the plantations on rotational basis. However, increment has continued to fall after 25 years in all density classes. This again, indicated that if objective of forest management is to maximise wood production than an early thinning, pre-commercial thinning should be done before 25 years and the final harvest between 35 and 40 years of age is probably appropriate (Punches, 2004).

The present issue ahead is how to manage the current plantations of the study sites and other similar plantations. The thinning guidelines for *P. patula* plantations suggested 45 years' rotations when existing stocks were between 800 and 1100 stems ha^{-1} (NACRMLP, 2006). This was prescribed when the plantation was between 25 and 30 years of age. But the current stocking is measured between 350 and 900 ha^{-1} and have crossed 35 years. Based on the community and topographical conditions of the forest area, it is suggested to carry out 1 more thinning to reduce stand density by 75–125 stems ha^{-1} within 45 years (in next 5 years) and obtain next rotation crop following shelterwood system since good potential for natural regeneration have already been observed in the study sites. Under this system, 10–40 potential mother trees per hectare should be retained in next five years and all of them to be harvested in next 10 years after new crop have been established. These mother trees are retained according to terrain and site quality and are removed gradually in secondary and final felling. In the case of new pine plantation, the viable rotation age is recommended to be 30±5 years of age with 2–3 thinnings.

Age affecting diameter increment

Apart from the analysis based on management systems, effect of age on diameter increment was judged through a simple linear regression which showed a strong correlation of r = -0.89 between diameter increments and age. This means increment of a tree decreases when tree gets older (Fig. 9). Normally, increment in a forest stand depends mostly onsite quality, and density and age. As all the study sites were in almost same aspect, altitudinal range and slopes, they were considered as similar site qualities. In a similar site quality and stand density, increment depends on age as the younger trees give higher increment than older (Kazmierczak, 2013). In the current study, average annual increment (AAI) was retarded after four years of plantations (Fig. 9). The increasing increment until this age could be due to the adoption of standard plantation methods where early pitting and composting was done that served as nutrient for at least four years as the plantations were carried out in highly degraded land (Kharel *et al.*, 2016). The diameter increment declined after the plantations reached four years. This may be due to loss of soil fertility and increasing stand density as the plantations were carried out at a spacing of 2 to 2.5 meters (Kayastha *et al.*, 2002), and plant competes for light when they are dense that result height increment than the diameter as height growth diminishes as stocking diminishes (Mason, 2005). Similarly, due to competition, trees with same diameter are taller in a denser stand (Zeide *et al.*, 2002). However, the significance tests suggested that when tree grows and passes its age, the rate of increment retards and become insignificant. The logarithmic projection of increment (Fig. 9) forecasted the insignificant increment after 45 years however major fall observed after the plantations have crossed 31 years of age. Similar result was observed in *P. patula* plantations in Australia (Binkley, 1985). In this study, the annual increment in radius was estimated almost three quarters of mm after 31 years which suggest not to keep these trees longer to attain growth (Ramprakash, 1986). The small increment could be insignificant and opportunity cost could be high after 30–35 years .In ideal situation as per international practices and based on earlier study result conducted in Nepal, they should be final felled at 30±5 years. Due to the delayed thinnings and in the absent of execution of complete package of thinnings, an extended rotation age of 45 years was recommended for the same plantations (Hunt *et al.*, 2001), for which existing stems were to be reduced to 75–125 stems ha^{-1} at 30–35 years and 50 stems ha^{-1} at 40 to 45 years of age, respectively.

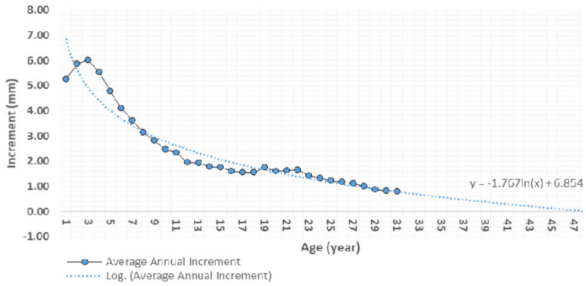

Fig. 9: Average annual increment with trend line: The trend line showed the increment reached almost zero at the age of 47 years of age.

This is also supported by the estimation of cumulative diameter increment (Fig. 10) where annual increment is cumulatively added by almost three quarters of mm and the curve is nearly horizontal after 42 years. The accumulation of radial increment was more than 2 mm before 27 years of age which retarded to 1.58 mm at 31 years of age. The projected increment is almost 0.2 mm at 42 years and almost 0.1 at 50 years which is highly insignificant.

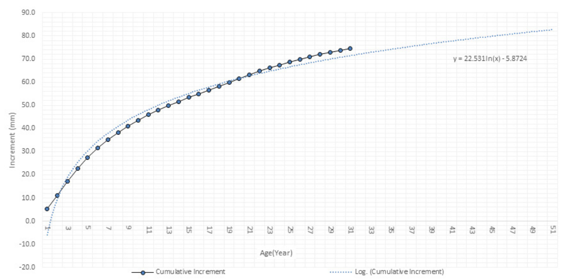

Fig. 10: Overall cumulative increment

In addition to age, the decreasing rate also influences by stand density. In a stand with density between 600 to 900 stems ha^{-1}, the average radial increment at 31 years' age was measured to be 0.4 mm where as it was 0.79 for overall average stand densities. The estimate of MAI also showed a similar pattern as it was high (2.4 mm) in overall average stand densities and low (2.2 mm) at the age of 31 years. This has been the evident of effect of density on increment at the same age.

The aggregated analyses of radial increment with different stand densities over passing age (Fig. 11) showed that with the increasing age, the radial increment rate decreases in all density classes. The reduction in radial increment rate was found to be almost equal until the age of 8–10 years in all the stand density classes which is similar to the result obtained in the study conducted in 2001 (Hunt, Dangal, & Shrestha, 2001).The decreasing rate was noticed to be higher in the high stand density (600–900 stems ha^{-1}) after 12 years.

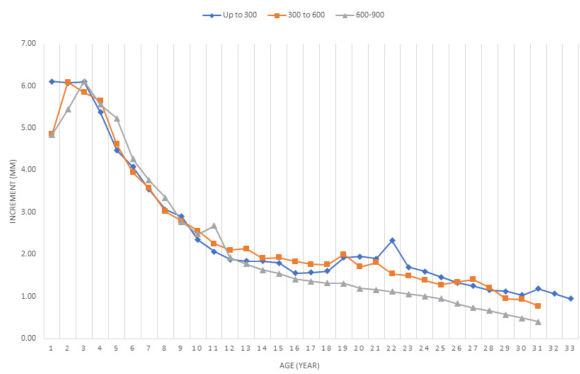

Fig. 11: Decrease in annual increment in different density classes

The sharp increase in annual increment in the second year in two density classes might not be due high density but could be due to the quality of seedling as well as the micro-climate during the plantation. However, there was a continuous fall in increment in the high stand density class except a small increment around 11 years. The fluctuations in the curve of low and medium stand density after 10 years could be due to the effects of thinning carried out in different years in different block of forests (Dharapani CFUG, 2007) & (Lankuri CFUG, 2000) whereas no such fluctuation was seen in higher stand density.

In an ideal scenario, rotation age to achieve maximum volume is fixed at the age where the curves of cumulative increment become high (Ramprakash, 1986).

The study conducted in 2001 and 2015 suggested that after certain age, cumulative increment decrease faster in higher stand density classes (Figure 12 and 13) which becomes almost horizontal and annual accumulation of biomass becomes almost one third of millimeter when it passes 30 years (Fig. 13). The result indicated that, these forests should be clear felled before 40 years to attain maximum growth which is not far from international practices. For example, in US, for Southern pine, a maximum age of final harvested was recommended to be 40 years of age (Demers *et al.*, 2016). Similarly, a rotation age of 35 years with 4 high intensity thinnings has been practiced in Kenya (KEFRI, 1997) whereas in the USA, *P. radiata* stands were managed up to three thinnings depending on potential productivity. This involves two thinnings to give a final crop stocking of 200 stems ha^{-1} at age 22 years and clear felling occurs at the age of 30 years (Berg, 1973).

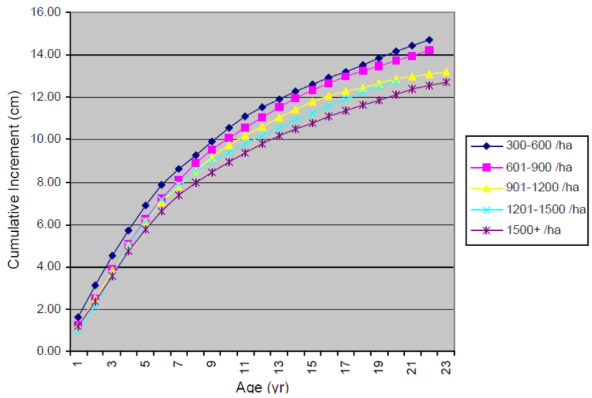

Fig. 12: Cumulative increment measured in 2001

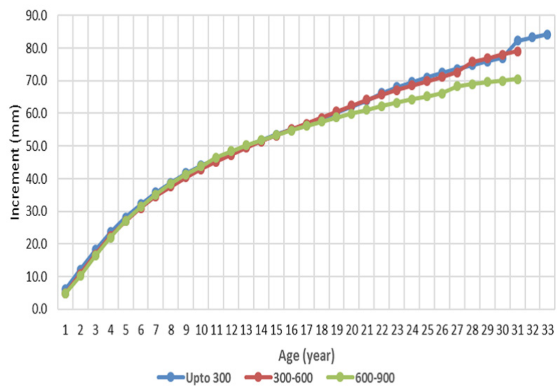

Fig. 13: Cumulative increment measured in 2015

Conclusion and management implications

The study assessed the effect of the age and management practices on radial increment of trees. From the findings of the present and past studies in same areas and supporting evidences from study conducted in other countries, it can be concluded that the radial increment in *P. patula* plantations declines with age *i.e.* when tree gets older, the increment declines accordingly. Moreover, the decreasing rate depends on the stand density. The rate of decline in increment is higher in high density classes. However, the increment rate does not affect by stand density in early stage of plantations *i.e.* 10–20 years. Management practices in plantations have significant role in increment as the study showed that improved management practices yielded more increment than the conventional forest management practices. The findings suggest the need for proper management practices in pine plantations to tap highest increment potential. Based on the findings and conclusions, the following recommendations are offered.

- Gradual and systematic removal of trees is required after 8–10 years of plantations to provide sufficient spaces for light and nutrient. Thinnings after 25 years is not required as late thinning has less effect.
- If systematic thinnings are carried out from the beginning, the final felling of plantations should be done in an age of 30±5 years to received highest volumes. However, final feeling should be carried out after new crop has been fully established if natural regeneration followed.
- For the existing plantations, they can't be removed at once though they have crossed rotation age of maximum volume. They should be completely removed in the next 10 years with two felling. However, they should be replaced by a new crop of the same or mix species before final felling. Phase wise removal is proposed for these plantations for which all the stock should be reduced to 75–125 stems ha^{-1} immediately. After five years from now, shelterwood system should be followed to allow natural regeneration for which only 10–15 potential seed trees per hectare should be kept. When new crop have been established, the potential seed trees should be removed.
- Intensive care should be given to protect forests from fire and grazing.

References

Berg, P. (1973). Silviculture of Pinus Radiata Stand Edge Trees at Woodhills Forest. *NZ G Journal of Forestry* **18 (1):** 115–123.

Binkley, C. S. (1985). *When is the Optimal Economic Rotation Longer than the Rotation of Maximum Sustained Yield?* Lakenburg, Australia: International Institute for Applied Systtems Analysis. Retrieved from http://pure.iiasa.ac.at/2691/ [5 March 2017].

Chand, P. B., & Ghimire, K. (2006). Unlocking the Value of Pine Forests for Sustainable Livelihoods: A case Study from Hille Jaljalle 'Ka' Community Forest in Kavrepalanchok District of Nepal. In *Managing Forest for Poverty Reduction: Capturing Opportunities in Forest Harvesting and Wood Processing for the Benefit of the Poor*. Ho Chi Min City, Vietnam: FAO.

Collett, G., Chhetri, R., Jackson, W. J., & Shepherd, K. R. (1996). **Socio Economic Impact Study.** Nepal Australia Community Forestry Project. Kathmandu, Nepal.

De Bell, D. S., Keyes, C. R., and Garner, B. L. (2001, February). Wood Density of Eucalyptus saligna Grown in Hawaiian Plantations: Effect of Silviculture Practices and Relation to Growth Rate. Australian Forestry, 64(2), 106–110.

Demers, C., Andreu, M., McGowan, B., Long, A., and Jarek, N. (2016). Thinning Southern Pines- A Kay to Greater Returns. IFAS Extension, SSFOR24, pp. 1–5. http://edis.ifas.ufl.edu.[15 August 2016].

Demers, C., Andreu, M., McGowan, B., Long, A., and Nowak, J. (2016, March). Thinning Southern Pines- A Key to Greater Returns. IFAS Extension-SSFOR 24. Florida, Florida, USA: University of Florida, School of Forest Resources and Conservation Department. http;//edis.ifas.ufl.edu [12 July 2016].

Dharapani CFUG. (2007, November 20). **Dharapani HIle Community Forest Management Plan 2064/65.** Chaubas 6 &7, Kavre District, Nepal.

DoF-a. (2012). **Community Forest Data Base.** Community Forestry Division of Department of Forest, Ministry of Forest and Soil Conservation, Kathmandu, Nepal.

Dwivedi, A. (1993). **A Text Book of Silviculture.** : R.O. Singh Gahlot For International Book Distributers, Dehra Dun, India.

Eijnatten, J. V., Acharya, H., and Shrestha, S. (2001). **Organisational Change in Four CFUGs Operating the Chaubas-Bhumlu Community Saw Mill.** Nepal Australia Community Resource Management Project, Kathmandu, Nepal.

Evans, J. (2000). Sustainability of Productivity in Successive Rotation. In *Timber Plantation Development.* Manila, Philippines: FAO. http://www.fao.org/docrep/005/AC781E/AC781E11.htm

FAO (2010). Plantation Report (online). Food and Agriculture Organisation, Rome, from www.fao.org: http://www.sifi.se/wp-content/uploads/2010/10/FAO-Plantation-Report.pdf.[3 August 2013].

Gerelbaatar, S., & Baatarbileg, N. (2011). Growth of scotch Pine (*Pinus sylvestris L.*) plantation in Northern Mongolia. *Journal of Agriculture and Technoogy*, 1205–1210.

Gilmour, D., King, G., Applegate, G., & Mohns, B. (1990). Silviculture of plantation forest in Central Nepal to maximise community benefits. *Forest Ecology and Management*, 173–186.

Hunt, S., Dangal, S., & Shrestha, S. (2001). **The Impact of Stocking on the Growth of Pine Plantations in the Mid Hills of Kabhre Palanchok and Sindhu Palchok.** Nepal Australia Community Resource Management Project. Kathmandu, Nepal.

Jackson, J. K. (1994). **Manual of Afforestation.** Forest Research and Survey Centre, Ministry of Forest and Soil Conservation, Kathmandu, Nepal.

Kayastha, B., Pradhan, S. L., Rasaily, N., Dangal, S., & Frans, A. (2002). **Marketing for Timber and Non-Timber Forest Products-2001.** Nepal Australia Community Resource Management Project, Kathmandu, Nepal.

Kazmierczak, K. (2013). The Current Growth Increment of Pine Tree Stands Comprising Three Different Age Classes. *Lesne Prace Bedawoze* **72 (2):** 93–100. doi:10.2478/frp-2013-0009

KEFRI. (1997). Silviculture of Pine (Online). Kenyan Forest Reseach Institute, Foret Department Karura,Kenya.http://www.fernis.net/system/files/current_silviculture_regime.pdf [2 May 2013].

Kharel, K. B., Kunwor, G. D., Thapa, S. B., Tamang, C. S. and Kunwor, L. B. (2016, May 17). Key Informant Interview. (S. P. Dangal, Interviewer)

Lankuri CFUG. (2000, June 19). **Lankuri Pakha Bhulbhule Kanchopat Bari CF Operational Plan.** Chaubas 1,3&4, Kavrepalanchok, Nepal.

Mason, E. G. (2005, February). A Brief Review of teh Impact of Stand Density on Variables Affecting Radiata Pine Stand Value (Online). Christchurch, Canterbury, New Zealand. http://www.fore.canterbury.ac.nz/euan/spacing/density3.htm.[24 June 2016].

NACRMLP. (2006). **Thinning Guidelines for *Pinus Patula* and *Pinus Roxburghii* Plantations in Nepal.** Canberrra Australia: Nepal Australia Community Resource Management and Livelihood Project managed by URS Sustainable Development.

NEA. (2011). **Initial Environmental Examination.** Nepal Electricity Authority, Kathmandu, Nepal.

Punches, J. (2004). *Thinning: An Important Forest Management Tool.* Roseberg, Oregon. Oregon State Univeristy- Extension services.

Ramprakash. (1986). **Forest Management.** International Book Distributer, 9/3 Rajpur Road, Dehra Dun 248001, India.

Razali, N. M. and Wah, Y. B. (2011). Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling Testts. *Journal of Stastistical Modeling and Analysis*, **2 (1):** 21–33. amazonaws.com/academia.edu.documents.

Sharma, S. P. (2012). Brief Analysis of Community Forest in Nepal. *Hamro Ban 2011/2012*, 18–24.

Silva, L. N. and Dudley, N. (2009, June). Ecosystem Integrity and Forest Plantations: Technical Paper. WWF International; Malaysia-Sabah Forest Department; State Forest Administration China; UK Forestry Commission.

Stock, W. D., Bourke, L. and Froend, R. (2012). Dendroecological Indicators of Historical Responses of Pines to Water and Nutriend Availability on a Superficial Aquifer in South-Western Australia. *Forest Ecology and Environment*, **264:** 108–114. doi:10.1016/j.foreco.2011.09.033

Subedi, V. R. (2011). *Forest Management Opportunities and Challanges in Nepal.* Nepal Forester Association, Kathmandu, Nepal.

Timilsina, N. (2005). *Supporting Livelihoods Through Employment: The Chaubas-Bhumlu Community Saw Mill, Nepal.* Forest Action, Kathmandu, Nepal.

Zeide, B. and Vandershaat, C. (2002). The Effect of Density on the Height- Diameter Relationship. *Eleventh Bieddial Southern Silviculture Research Conference* (p. 622). Asheville, NC: US Department of Agriculture, Forest Science, Southern Research Station, USA.