Secondary forests are becoming an integral component of the tropical forest landscapes. Due to their role in providing ecological services, economical returns, cultural values and aesthetic importance, scientific studies on these forests is gaining momentum. Secondary forests can be defined as 'forests regenerating after partial or complete removal of tree component due to anthropogenic factors e.g. logging, shifting cultivation, clearance for settled agriculture and human settlements etc., which significantly alters the overall community structure as well as the species composition'. They have been classified based successional stages, vegetation types, ownership patterns, land use history, and nature of influence.

The present study was carried out in the secondary forests in and around Namdapha national park, in the Changlang district of Arunachal Pradesh. They are regrowing on abandoned agricultural land, past human settlement areas and forest fallows and can be placed under post-extraction and post-abandonment categories.

The major objectives of the present work were to: (i) characterize the vascular plant diversity in the secondary forests, (ii) study the regeneration ecology of some of the important tree species and, (iii) identify the factors affecting regeneration of some important tree species. The major findings have been summarized in the foregoing sections.

- Floristic diversity was higher in the secondary forests (180 species, 144 genera and 66 families) as compared to the primary forests (160 species, 117 genera and 62 families).
• Overall species similarity between the primary and secondary forests was 21.2%. The tree species exhibited 53.2% similarity, shrub species 21.8%, and herb and climber species exhibited 20.6% similarity. Similarity in canopy tree species between the primary and secondary forests was 65%, while for middle and lower storied trees the similarity was 50% and 48%, respectively.

• Tree density between the primary and secondary forest did not differ significantly. Shrub density is significantly higher in the primary forest than the secondary forest and the density of herbs is greater in the secondary forests than the primary forests.

• Amongst trees, *Ostodes paniculata*, *Saprosma ternatum* and *Altingia excelsa* were commonly encountered (>50% frequency) in the primary forests, whereas *Dysoxylum reticulatum* and *Alangium chinense* were frequently encountered in the secondary forest stands (>47% frequency). Amongst shrubs, high frequency was observed were for *Elatostemma platyphyllum*, *Sarcandra glabra*, *Phlogacanthus asperulus*, *Myrioneuron nutans* and *Psychrotia silhetensis* in the primary forests and in the secondary forests *Sida acuta*, *Debregesia longifolia*, *Strobilanthes secundus*, *Leea compectiflora* and *Clerodendrum colebrookianum* were frequent. On the forest floor, *Adiantum caudatum*, *Forrestia mollissima*, *Dryopteris sparsa*, *Piper mullesua*, and *Commelina paludosa* were frequent in the primary forests, while in the secondary forests the occurrence of *Ageratum conyzoides*, *Spilanthus paniculata*, *Oxalis corniculata*, and *Paspalum conjugatum* was frequent.

• Tree basal area was higher in the primary forest stands (55.7 - 78.58 m² ha⁻¹) than that of the secondary forest stands (29.22 – 35.26 m² ha⁻¹). Species sharing most part of the basal area in the primary forests were *Altingia excelsa*, *Terminalia myriocarpa*, *Terminalia myriocarpa*,
and *Mesua ferrea*, while in the secondary forests *Phoebe lanceolata, Dysoxylum reticulatum, Alangium chinense, Albizia procera, Actinodaphne obovata* and *Dendrocalamus hamiltonii* had a major share.

- Both the primary as well as secondary forests displayed more than 95 percent clumped distribution of species. Only 3 to 4 percent exhibited random distribution. None of the species in the primary and secondary forest sites displayed regular distribution.

- The $\alpha$ diversity for tree and shrubs was higher in primary forest than the secondary forest. For herbaceous species, the trend was reverse. Shannon-Weiner index for the tree species was higher in primary forests than the secondary forests. The reverse was true for shrubs and herbs. The Simpson's dominance index for trees, herbs and climbers was more in case of secondary forests than the primary forests. In shrubs, the dominance index was more in the primary forests as compared to secondary forests. Pielou's evenness index for trees was higher in the primary forests than the secondary forests. For shrubs and herbs the index was higher in the secondary forests than the primary forests. In general, the evenness index values were low indicating uneven distribution of different species.

- The secondary forests showed more habitat variability than the primary forests, which is characterized by high $\beta$ diversity between the stands SF1 and SF3 (1.82), PF2 and SF3 (1.81) and PF1 and SF3 (1.80). PF1 and PF2 had the lowest $\beta$ diversity value of 1.55.

- The density-girth distribution pattern of trees shows that the secondary forests had more number of individuals in the lower girth classes' (i.e. 11-20 cm and 31-60 cm)
than the primary forests. The number of individuals in the higher girth classes (>91 cm) was more in the primary forests.

- The secondary forests exhibited better tree regeneration than the primary forests. About 66% of the total regenerating species were in the secondary forests as compared to the latter, where only 50% species were regenerating. 41% of tree species in the secondary forests were not regenerating through seeds while in the primary forests such species constituted only 48%.

- Seedling populations in all the primary and secondary forest stands showed marked differences between wet (June-July) and dry (November-December) seasons with more number of tree species in the seedling stage in the wet season.

- Coppice regeneration was found only in the secondary forest stands and was predominant in SF3 with 50% of the species regenerating through coppicing.

- Stump girth size significantly affected sprouting in *Alangium chinense*, *Alstonia scholaris*, *Albizia procera* and *Melia azedarach* (*p*<0.001). Average number of sprouts was more in the girth classes of 90-120 cm and 121-150 cm.

- Density of coppice shoots had a significant effect over diameter and height of the shoots (*P*<0.05 to *P*<0.001) for all the selected species except *S. mukkorossi*. Average diameter and height of shoots was comparatively more in the stumps having less number of shoots. The number of stumps having sprout density ranging from 1-10 was more in case of *A. chinense*, *A. scholaris*, *M. azedarach* and *S. mukkorossi*.

- Flower and fruit production varied significantly across girth classes, stands and years. Flower and fruit production was higher in the secondary forests for *Alangium chinense*, *Sapindus mukkorossi* and *Spondias axillaris*, while for *Shorea assamica*
and *Mesua ferrea* it was higher in the primary forest. In all the species, production was higher in the year 2004.

- Seed dispersal in the selected species was primarily through gravity. But, height of release of samaras significantly affected settling time as well as dispersal distance in case of *Shorea assamica*. Pearsons’ correlation coefficients showed significant negative relationship of seed weight with settling time and wing loading (*p*<0.05; one-tailed), whilst significant positive relationships were established between wing area and settling time and seed weight, dispersal distance with settling time and wing area, and wing loading with settling time, seed weight and wing area.

- Post-dispersal seed fate experiment showed that a large proportion of the seeds of *Spondias axillaris* and *Mesua ferrea* disappeared due to seed predation by ungulates and wild boar in the primary forests. In the secondary forests, most of the seeds of *Alangium chinense* and *Sapindus mukkorossi* lay dormant. Maximum seed germination was observed in case of *Shorea assamica*.

- Seed viability of the selected species decreased consistently across a temporal scale. *Shorea assamica*, *Mesua ferrea* and *Spondias axillaris* recorded viability periods of 10 days, 48 days and 36 days respectively. Propagules of *Alangium chinense* and *Sapindus mukkorossi* maintained viability of 65 and 200 days respectively.

- The *in situ* seed germination showed that stand quality characterised by canopy openness significantly affected seed germination in all the species (*P*≤0.001), whereas litter depth did not have any effect over seed germination in all the species studied.

- The *ex situ* seed germination experiment showed that the percentage of seed germination was more in case of the heavier seeds, as compared to the lighter ones in
all the species but, statistically seed germination in all the study species was significantly affected by differences in light levels \((p<0.05\) and \(p<0.005\)) and not by seed weight (except *Shorea assamica* - \(P<0.05\)).

- Seedling recruitment for *Sapindus mukkorossi* and *Spondias axillaris* was higher in the secondary forests than in the primary forests. For *Shorea assamica*, seedling recruitment was higher in the primary forest. Year wise, the seedling recruitment for all the species was higher in the year 2004 than in the year 2003.

- High seedling mortality of *Alangium chinense* and *Sapindus mukkorossi* occurred during first three months of germination. However, the seedling survivorship curves for *Mesua ferrea* and *Shorea assamica* showed a sharp reduction in the number of surviving individuals after 3 months period and continued till the seedlings were one year old, after which the seedling population stabilized.

- The seedling mortality rate of *Alangium chinense* was negatively correlated with soil temperature \((p<0.05)\), while that of *Sapindus mukkorossi* it was correlated with light intensity \((p<0.05)\) in the secondary forest stand. The mortality rate for *Spondias axillaris* was positively correlated with light intensity \((p<0.05)\) and negatively correlated with soil moisture in the secondary forest. Seedling mortality for all the species was more under canopy of the parent tree than the peripheral area.

- Relative growth rate in height and leaf area of *Sapindus mukkorossi* and *Spondias axillaris* was higher in the secondary forest as compared to the primary forest. On the other hand, for *Shorea assamica* the relative growth rate was more in the primary forest than the secondary forest. The relative growth rate in seedling height and leaf
area reflected a strong seasonal influence with maximum growth in the rainy season (June-July) and least growth in the winter months (December-February).

- The seedling size, seedling morphology and biomass accumulation of all the species varied significantly under different light and nutrient levels. Height, leaf area and collar diameter for *Alangium chinense* was highest at high light intensity (65%) while for *Sapindus mukkorossi, Spondias axillaris, Mesua ferrea* and *Shorea assamica* it was highest at intermediate light intensity (45%). All selected species responded vigorously to increased level of nutrients (30 and 35 gms of NPK) mostly under 45-65% light levels.

- All the species exhibited similar patterns of biomass accumulation under different light and nutrient treatments with a general trend of increasing biomass allocation to stems, leaves and roots with increasing light. Root biomass decreased with increasing nutrient concentration irrespective of light intensity in *Sapindus mukkorossi* and *Spondias axillaris*. In case of biomass allocation to leaves and stems an increasing trend was observed in all species with increasing nutrient concentration irrespective of light levels.

- In *Sapindus mukkorossi* and *Mesua ferrea*, maximum total plant biomass was obtained at 45% light; whilst in *Alangium chinense* total plant biomass was highest at high nutrient level (*N₄*) at 65% light. In *Sapindus mukkorossi* root biomass was highest at low nutrient level (*N₇*) while stem and leaf biomass was highest under high nutrient level (*N₄*). Root biomass in *Spondias axillaris* was highest at low nutrient level (*N₁*) whilst stem and leaf biomass was highest at higher nutrient level (*N₄*). For *Mesua ferrea* root, stem and leaf biomass were highest under high nutrient level (*N₄*).
In *Shorea assamica* leaf and stem biomass values were highest at N4 nutrient level while highest root biomass values were obtained at low nutrient level (N1).

- Relative growth rate in terms of height and leaf area increased consistently across light and fertilizer gradients. Relative growth rate in height increased along the fertilizer gradient and was highest at 65% light for all species while the relative growth rate in leaf area was highest under intermediate light intensity (45%) in all the species except *Alangium chinense*.

- Overall, LMR and SMR showed an increasing trend with increasing light and nutrient levels; but RMR, SLA and LAR exhibited a decreasing trend with corresponding levels of light and nutrient. Most of the derived growth parameters for all the selected species varied significantly within and between different fertility as well as light levels. But fertility level did not affect LAR in *Spondias axillaris*. Similarly RMR, LMR, SLA and LARMR were not affected significantly by light, nutrient or the interactive effects of the two in case of *Mesua ferrea*. In case of *Shorea assamica* also variation in light levels did not have significant effect over SMR.

- The β values in the multiple regression analysis shows that both light and nutrient have significant role in seedling growth in terms of relative growth rate in height and leaf area and total plant biomass accumulation. In case of *Alangium chinense*, *Sapindus mukkosossi* and *Shorea assamica* light intensity influenced RGRH, RGRLA and total plant mass more significantly than nutrient level. But in *Spondias axillaris* and *Mesua ferrea* nutrient levels more significantly influenced RGRLA and total plant mass than light levels respectively.
Considering the responses of various constituent species, it may be concluded that for faster recovery of secondary forests, manipulation of light and nutrient levels may be introduced. Based on the findings of the study following may be concluded:

- The differential disturbance history had significant impact on the community structure, species composition and regeneration processes of the secondary forests.

- The structure of primary and secondary forests significantly different, which was a function of prevailing microenvironment, nutrient availability and events during regeneration phases of the dominant species. All these factors, in turn, were also influenced by the community structure.

- The secondary forests were species-rich and had better regeneration than the primary forests. However, due to past disturbance history, the community characteristics in these forests were relatively less complex than those of the matured primary forests.

- The species had differential response to primary and secondary forest environments, which was both during adult as well as regenerating phases.

- Based on the response of the species during the regenerating phase to two different forest environments, the future forest composition could be predicted.

- Considering the species response to primary and secondary forest environment as well as the species characteristics, *Mesua ferrea* and *Shorea assamica* may be classified as primary species, *Alangium chinense* and *Spondias axillaris* as early successional species and *Sapindus mukorossi* as mid-successional species.