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Assessment of invasion of *Ageratina adenophora* in the plantation forest of Nepal

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Large-scale plantations of pine species were done in the bare hills of the Middle Mountain region of Nepal during the early 1980s. There is a growing concern on the sustainability of the planted pine forests in the country due to the presence of invasive alien plant species (IAPS). Invasive alien plant species are considered as one of the drivers of forest degradation and deforestation. *Ageratina adenophora* is one of the problematic IAPS found in the planted pine forests throughout the country. In this study, we employed different treatments to control the invasion of *A. adenophora* in the planted pine (*Pinus patula*) forest. The research design included four different treatments, *viz*., (i) control, (ii) stem felling, (iii) floor clearance, and (iv) stem felling cum floor clearance in one block (Block I), which was replicated in another block (Block II). The data were collected using circular sample plots with 2m radius. The ANOVA and TukeyHSD Tests were applied during the analysis process so as to determine the effects of treatments on invasion of *A. adenophora*. The "floor clearance treatment" was found to be significantly effective to reduce the presence of *A. adenophora* in the planted pine forest. On the contrary, the "opening of forest cover treatment" was found to be conducive to this invasive species to invade the area. The "stem felling cum floor clearance treatment" could be an effective strategy to control invasion of *A. adenophora* in planted forest, but as it demands a high cost, it is likely to be appropriate for small forest areas where promotion of regeneration is of high priority.

Keywords: *Ageratina adenophora*, floor clearance, invasion, *Pinus patula*, treatment

Large scale plantation program was initiated in the Middle Mountain region of Nepal during the early 1980s (Gilmour *et al.,* 1990). More than 370,000 hectares of plantations in the bare hills were successfully established with different pine species including native *Pinus roxburghii*, *P. wallichiana* and alien *P. patula* (DoF, 2012) as these species can survive and grow well on the areas with very poor soil (Jackson, 1994).

According to the FAO (2015), World's planted forest has increased by over 105 million ha since 1990 resulting in seven percent of the total forests. According to the then Nepal Australia Community Resource Management and Livelihood Project (NACRMLP), a total of 23,404 hectares of plantations had been established in the Sindhupalchowk and Kabhrepalanchok districts of Nepal since the late 1970s (NACRMLP, 2006), mostly dominated by pine species (Hunt *et al.,* 2001) among which *P. patula* covers almost 75% of the total pine plantations (ERI, 2011).

Planted forests share many ecosystem services produced by native mixed forests, but the extent

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of sharing is determined by its management (Vihervaana *et al.*, 2012). Both the plantations and natural forests have advantages and disadvantages. However, there is a growing concern on the sustainability of planted forests (Powers, 1999), and some of the issues associated with the stands of pure and mixed species have been still undetermined (Jactel *et al.,* 2002).

According to the latest forest resource assessment in Nepal, almost 45% of land is occupied with forest cover, including planted and natural forest (DFRS, 2015). However, forest degradation and deforestation has undergone due to many reasons. Invasive alien plant species (IAPS) are considered as one of the drivers of forest degradation (MFSC, 2009), threat to biodiversity conservation (MFSC, 2014) and has adverse effect on forest regeneration (Shrestha, 2019a).

Invasive alien species have negatively affected forest ecosystems, wetlands, protected areas and agro-ecosystems by threatening both biodiversity and people's livelihood (MFSC, 2014). The impact of invasive alien species is further worsened by ongoing climate change resulting in increase of frequency and intensity of biological invasion (Simberloff, 2000) and severe impact on high altitude forest (Wang *et al*., 2019) . Limited studies have presented the ranges of impacts of IAPS from habitat degradation of endangered wildlife, e.g., one-horned rhinoceros (Murphy *et al*. 2013) to problems in the livelihood of rural communities (Rai *et al.,* 2012; Shrestha *et al.,* 2019b). It has been considered globally as the second major cause of biodiversity loss after habitat degradation (Glowka *et al.,* 1994; Bellard *et al*., 2016).

There are, altogether, 26 IAPS in Nepal, and *A. adenophora* is one of them. It is commonly found in forest, shrub land, grassland and agroecosystem at the altitudinal range of 400–2600m (Shrestha, 2019). The invasion of *A. adenophora* is more severe at the edges of the forest and agricultural lands and also the wetlands (Baral *et al.,* 2013). In forest and shrub lands, *A. adenophora* is considered as one of the major problematic species including *Chromolaena odorata, Lantana camara* and *Mikania micrantha* (Shrestha, 2019a). Management of invasive species involves three basic strategies i.e. prevention, eradication and control (Radocevich *et al.*, 2009). Effects of invasion and initiatives to manage IAPS and studies on their dynamics have been very limited (Bhatterai *et al.*, 2014). Therefore, this study focused on assessing different treatments which help control invasion of *A. adenophora* in the planted pine forest.

Methods and materials

Study area

The study was carried out at two sites within the Sangaswoti Deurali Lauri Community Forest (SDLCF) of Kabhrepalanchok district (Bagmati Province) situated in the middle-hill region of Nepal (Figure 1).

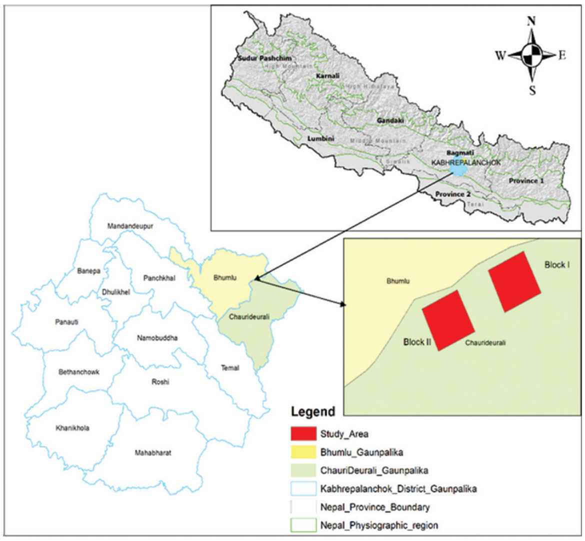

Figure 1: Location of study sites in Kabhrepalanchok district of Nepal

The SDLCF is located at an altitude of over 2200m from the sea level, and is dominated by *P. patula* associated with a few other tree species. The study sites consist of mainly the pine species planted in the early eighties. The mature stocks of *P. patula* and *P. wallichiana* were present in the study sites; around 95% of the stems were of *P. patula*. The practice of open grazing before the study had led the area prone to biological invasion. The forest grounds of the study sites were invaded mostly by invasive *A. adenophora*. In Nepal, distribution of *A. adenophora* is mostly absent in the Terai region (i.e. a wide belt of flat land along the southern border), and it occurs occasionally in the Siwalik region, particularly in western Nepal. The species is widespread in the Middle Mountain region (Shrestha, 2019a).

Two blocks (Block I and Block II), each with the area of 2 ha, were established within the SDLCF for the purpose of the study. Each block was further divided into four treatment-plots, each with the size of 0.5 ha (100m × 50m) at the spacing of 5m as buffer (Figure 2) so as to apply four different treatments, viz., (i) control, (ii) stem felling, (iii) floor clearance, and (iv) stem felling cum floor clearance (abbreviated with T_0, T_1, T_2 and T_3, respectively).

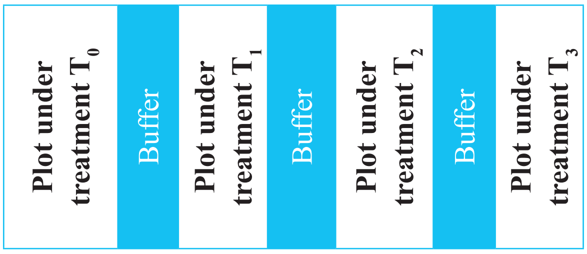

Figure 2: Establishment of treatment-plots within a block in the study sites

Note: T_0=Control, T_1=Floor clearance, T_2=Stem felling (10%), T_3= Stem felling (10%) cum floor clearance.

Data collection

After establishing the treatment-plots in the study sites, the aforementioned four treatments (T_0, T_1, T_2 and T_3) were applied every year for three consecutive years (FY 2073/074–2075/076). Circular sample plots of 2m radius were laid out systematically at the spacing of 10m × 5m (length × breadth) inside each treatment-plot to collect the coverage of *A. adenophora*. Altogether, 39 sample plots were established within the four treatment-plots to collect the necessary data. All the circular sample plots were divided into four parts at cardinal directions to record the cover percentage of *A. adenophora*. In between the treatment-plots, buffers of 5m width were created so as to neutralize the buffer effects on the plantations within the treatment-plots. The presence of *A. adenophora* in the treatment-plots was recorded on the basis of ocular estimation.

Data analysis

The data collected from the field were analyzed separately for each block. The coverage of the IAPS in each sample plot within each treatment-plot are highlighted in Figure 3. The mean and standard deviation of the coverage percent of the IAPS were calculated for all the treatment-plots. The significant effects of treatments in each block was determined by applying the ANOVA test. Besides, the TukeyHSD test was also applied to compare the means of the target variables. All the statistical analyses were conducted in R program (R Core Team, 2019). Similarly, the distribution of the IAPS, whether homogenous or heterogeneous in each treatment-plots, was analyzed in graphs (Figures 3 and 4). Moreover, the cost incurred for applying treatments in the blocks was also calculated using the number of labors and their per day rate as per the government norms; however, only the labor cost was considered in the analysis.

Results

Number of pine stems

In the establishment year, the number of pine stems in both the blocks were recorded. Every year, 10 percent of the stems were removed from the treatment-plots T_2 and T_3 within both the blocks in course of the application of treatments (Table 1).

Table1: Number of pine stems after the treatments in different years

Treatment	Before treatment		2015		2016		2017	
	Block I	Block II	Block I	Block II	Block I	Block II	Block I	Block II
Control (T_0)	205	212	205	212	205	212	205	212
Floor clearance (T_1)	192	159	192	159	192	159	192	159
Stem felling (10% per year) denoted by T_2	161	170	145	153	129	136	113	119
Stem felling (10% per year) cum floor clearance denoted by T_3	154	174	139	157	124	140	109	123

Distribution of A. adenophora

The distribution of *A. adenophora* was not similar in all the treatment-plots. The effects of treatment can be easily noticed in Figure 3 and Figure 4. The treatment-plots T_1 and T_3 followed some linear pattern as compared to the treatment-plots T_0 and T_2 with the lower level of the presence of *A. adenophora* in both the blocks. The results showed that the floor clearance work had important role in reducing the presence of *A. adenophora*.

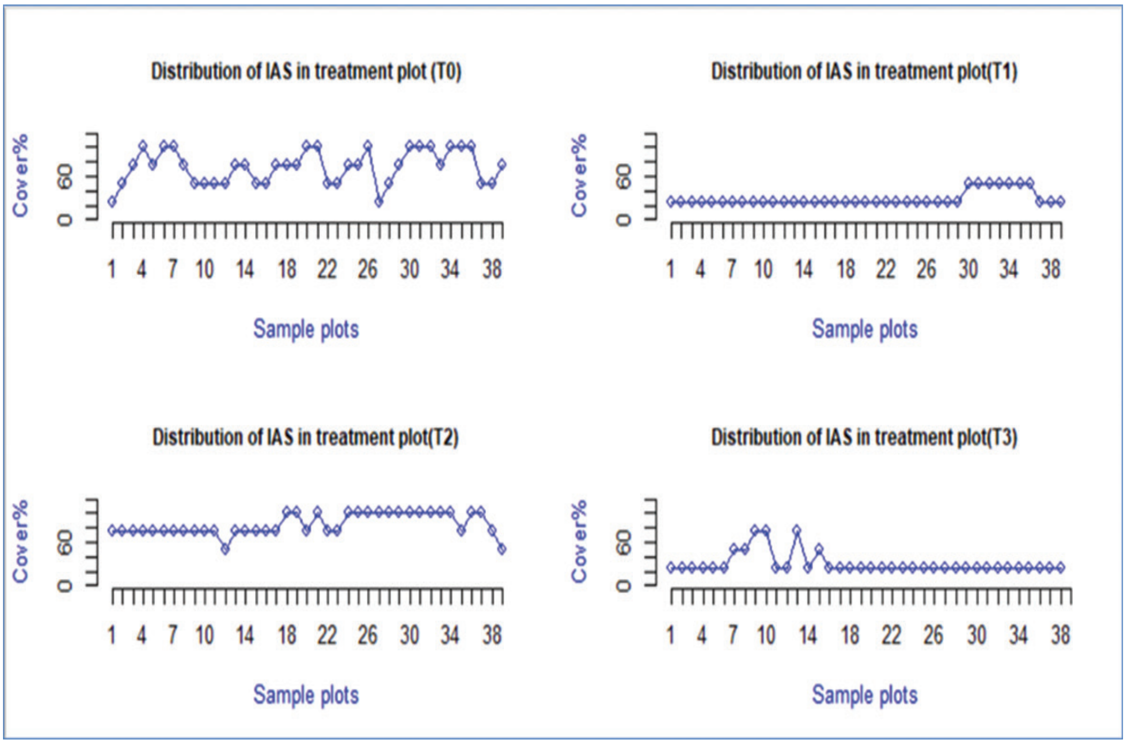

Figure 3: Distribution of *A. adenophora* in Block I

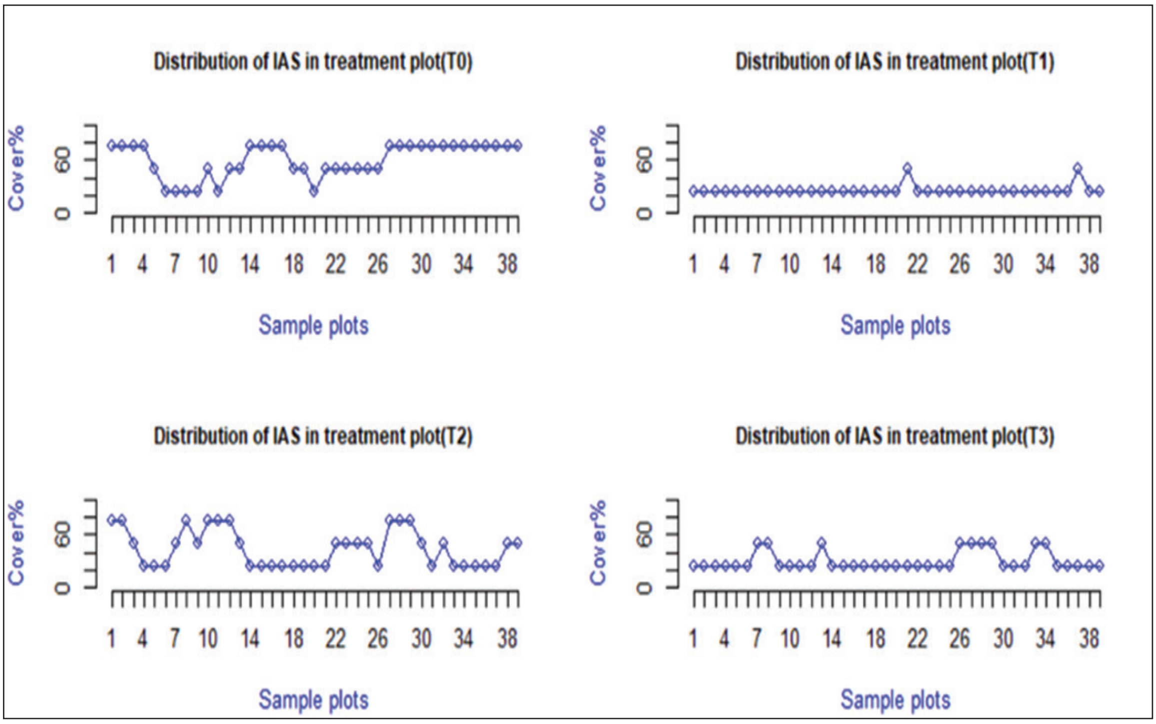

Figure 4: Distribution of *A. adenophora* in Block II

Coverage of A. adenophora

In the case of Block I, the mean coverage percent of *A. adenophora* was found to be the highest (59.61%) in the controlled plot T_0 followed by the treatment-plots T_2 (44.23%), T_3 (30.76 %), and T_1 (26.28%), respectively (Table 2). Similarly, the standard deviation of the coverage of *A. adenophora* was found to be the highest (20.24) in the treatment-plot T_2 followed by the controlled plot T_0 (18.68), and the treatment-plots T_3 (10.67) and T_1 (5.58), respectively within the same block.

Table 2: Mean and standard deviation of the IAPS coverage

Block	Treatment	Mean cover (%)
I	T_0	59.61 (18.68)
	T_1	26.28 (5.58)
	T_2	44.23 (20.24)
	T_3	30.76 (10.67)
II	T_0	72.43 (22.79)
	T_1	29.48 (9.71)
	T_2	83.97 (14.60)
	T_3	30.12 (14.74)

Note: Standard Deviations in parentheses

In the case of Block II, the mean coverage of the IAPS was found to be the highest (83.97%) in the treatment-plot T_2 followed by the controlled plot T_0 (72.43%) and the treatment-plots T_3 (30.12%) and T_1 (29.48%), respectively. Similarly, the standard deviation of the IAPS coverage was found to be the highest (22.79) in the controlled plot T_0 followed by the treatment plots T_3 (14.74), T_2 (14.60) and T_1 (9.71), respectively (Table 2).

The result showed that the mean coverage of *A. adenophora* was higher in the treatment-plots where floor clearance had not been performed. The effect of floor clearance work (either solely or accompanied with stem felling) had reduced the presence of *A. adenophora* in the study sites. The trend of the presence of *A. adenophora* in both the blocks was more or less similar.

The ANOVA Test indicated that there was significant effect of the "floor clearance treatment" on the presence of *A. adenophora* in both the blocks- Block I (f<2e-16) and Block II (f< 2e-16). It confirms that the floor clearance on the pine plantation forest helps reduce the presence of this invasive species significantly. On the other hand, the TukeyHSD Test in R Program (which was performed to test the multiple comparison of the means) showed that all the treatments were significant except T_3 and T_1 in both the blocks (Table 3). The treatment-plots T_1 and T_3 with the "floor clearance treatment" showed similar results.

Table 3: Comparison of the means of different treatments based on TukeyHSD Test

Block I				
Treatments	**Difference**	**Lwr**	**Upr**	**p adj**
T_1–T_0	–33.33	–42.17	–24.48	0.0000
T_2–T_0	–15.38	–24.22	–6.54	0.0000
T_3–T_0	–28.84	–37.69	–20.00	0.0000
T_2–T_1	17.94	9.10	26.79	0.0000
T_3–T_1	4.48	–4.35	23.33	0.5529
T_3–T_2	–13.46	–22.30	–4.61	0.0006
Block II				
Treatment	**Difference**	**Lwr**	**Upr**	**p adj**
T_1–T_0	–42.98	–52.46	–33.43	0.0000
T_2–T_0	11.53	2.02	21.05	0.0104
T_3–T_0	–41.51	–51.09	–31.93	0.0000
T_2–T_1	54.48	44.97	64.00	0.0000
T_3–T_1	1.43	–8.14	11.00	0.9799
T_3–T_2	–53.05	–62.62	–43.47	0.0000

Cost associated with removal of IAPS

The uprooting of *A. adenophora* including the removal of pine needles during floor clearance in the treatment-plots required significant labor cost. The cost incurred during the floor clearance treatment was NRs 13,800.00 (~ US $120) per ha per year. A total of 6 ha area was cleared in the treatment-plots in course of floor clearance during the study period of three years resulting expenditure of NRs 82,800.00 (~ US $720). The cost incurred in the removal of *A. adenophora* had, no doubt, contributed in lowering the presence of *A. adenophora* in the study sites (Table 4).

Table 4: Cost of treatment (floor clearance) for 3 years in the study sites

Block	Treatment	Cost/ha/yr. (NRs.)	Total area (ha)	Cost (NRs.)	*A. Adenophora* coverage (%)
I	T_0	-	-	-	59.61
	T_1	13,800 (~ US $120)	0.5 × 3 = 1.5	20,700 (~ US $180)	26.28
	T_2	-	-	-	44.23
	T_3	13,800 (~ US $120)	0.5 × 3 = 1.5	20,700 (~ US $180)	30.76
II	T_0	-	-	-	72.43
	T_1	13,800 (~ US $120)	0.5 × 3 = 1.5	20,700 (~$ US 180)	29.48
	T_2	-	-	-	83.97
	T_3	13,800 (~ US $120)	0.5 × 3 = 1.5	20,700 (~$ US 180)	30.12
Total			**6.0**	**82,800.00 (~ US $ 720)**	-

Discussion

Both anthropogenic and natural factors are responsible for the introduction and spread of IAPS (Rai *et al*., 2012). In order to control population of *A. adenophora*, one of the problematic IAPS, different control measures (i.e. biological, chemical and mechanical) have been in practice (Poudel *et al*, 2019). Manual removal of *A. adenophora* from the forest helps control its population to certain level than leaving the forest as it is. In the large area, it may not be feasible as it demands more budget. However, it can be financially viable for a small forest area that needs regeneration of native tree species.

Impact of invasive alien plant species on forest regeneration has been reported in many studies. It is shown that invasive species has stronger inhibitory effects on tree seedling establishment and growth compared to native understory species (Nilsson *et al*. 2000; Wallstedt *et al.* 2005). High abundance of *A. adenophora* inhibits the growth of seedlings of native canopy trees (Denggao *et al*., 2018), detrimental impact on local biodiversity and negative impact on local communities (Baral *et al.*, 2013). Thus, it is important to maintain the population of *A. adenophora* to minimize its detrimental effect on native tree regeneration.

Invasion of *A. adenophora* mostly occurs in open land such as grass land, agriculture land, open wood land, forest margins, etc. (Baral *et. al*., 2013) has reported that open areas are conducive for the establishment of *A. adenophora*, and it is the first species to colonize the degraded areas preventing other plants to grow. Our result also showed that the invasion of *A. Adenophora* had positive relation with the opening of forest. It was noticed that the opening of the forest by felling the stems triggered the IAPS to invade the area.

Floor clearance work is associated with the removal of *A. adenophora* and other pine needles in a pine plantation forest assuming that it controls the population of IAPS. Our results showed that the floor clearance work had significant effect on maintaining the population of *A. adenophora* at minimum level as compared to the other treatments. The floor clearance accompanied by stem felling did not produce better result than the floor clearance alone. Opening of forest (canopy gap) makes the environment favorable for IAPS to dominate other vegetation (Vargas *et al.,* 2013). On the contrary, increasing tree canopy closure in the forest suppress growth of IAPS (Khaniya & Shrestha, 2020). The best option to control the population of *A. adenophora* in pine plantation forest could be a periodic removal of this invasive species from the forest ground with least disturbance to canopy cover of the forest.

The cost associated with the removal of *A. adenophora* could be costly for large area in terms of labor cost. However, in the context of Nepal, most of the forests (47.5%) are managed by the communities belonging to 4.2 million households (DFRS, 2015; DoF, 2017). So, mobilization of communities could be a better option for rejuvenation of small degraded forest areas from IAPS. In this regard, Khania & Shrestha (2020) have also suggested to control IAPS through participatory way.

Conclusion

Invasion of IAPS in the forest area is a problem for the existence of native species. In the planted pine forest, invasion of *A. adenophora* is common in Nepal. The condition is further exacerbated when it gets conducive environment to spread all over. Invasion of *A. adenophora* has positive relation with the opening of forest cover. Creating gaps by stem felling in the planted pine forest offers IAPS to invade the area. In order to control its population, human intervention is vital. Periodic removal of this invasive species from the forest floor helps reduce its intensity of invasion. Floor clearance along with maintaining forest cover is one of the best means to control the population of *A. adenophora* at minimum level in the planted pine forest. The cost for floor clearance periodically in planted pine forest is high for the developing countries like Nepal. However, it could be applicable to small forest areas where the regeneration of desired species is of high priority.

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