Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-10, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Assessment of Invasive Alien Plant Species: Impact on Carbon Sequestration

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*Abstract***:** *Forest of lowlands in Nepal's Terai is heavily impacted by invasive plant species, particularly Mikania micrantha which is also considered as one of the high risks posed Invasive Alien Species (IAS). Understanding the effects of invasive species (IS) on carbon (C) stock in biomass requires identifying the IS and its impacts on population structure and C sequestration of the ecosystem. This study endeavours to assessment of invasive alien plant species impact in C sequestration in community forest of* Parsa Wildlife Reserve (PWR) of *Parsa district, Nepal. Systematic random sampling was used for assessing biomass and forest structure. The regeneration and sapling status of low, medium and high severity were estimated through density. Forest C was analyzed which included both above and below ground biomass C. Invasion of Mikania micrantha leads to unsustainable population of local species characterized by a conspicuous low number of regenerations in higher severity area. Total C did not differ between low (196.87t/ha), medium (157.23 t/ha) and high (129.16) severity level due to the preponderance of wood biomass in all sites. Eventually, this has contributed on C stock of the forest which also did not differ significantly between different levels of severity (p>0.01). These results indicate that the changes in the sequestration of C have occurred across the Shree Rotomate Deurali Buffer Zone Community Forest (SRDBZCF) following the widespread Mikania micrantha invasion. These losses of C have important implication for quantifying the effect of IS. Thus, a regular assessment and monitoring of the invasive weed Mikania micrantha is necessary to understand the problem and its impact on C pool of lowland forest of Nepal.*

Key words: *Biomass, carbon sequestration, density, invasion, Mikania micrantha*

Introduction

Invasive species (IS) are found in virtually all terrestrial ecosystems and are one of the most pervasive elements of global change biology (Vitousek, 1994). "It is an organism that has been moved from their native habitat to a new location where they cause significant harm to the environment, economic systems and/or human health" (Richardson et al., 2000a; Beck et al., 2008; Tiwari et al., 2005). The pace of the spread of invasive plant species (IPS) has increased with trade, travel and technology and they have now invaded forests throughout the world (Meyerson & Mooney, 2007; MEA, 2005). Indisputably, the exordium of incipient species into a forest alters the ecosystem properties and processes through the manipulation of plant species composition. IS, consequently, are considered one of the consequential drivers of ecosystem change and the second most earnest threat to natural habitats after habitat fragmentation and loss (MEA, 2005). The habitat fragmentation coupled with the plant species invasion is likely to accelerate species extinction in the biodiversity rich Himalaya regions in particular. Needless to say ecological negatives of IAS in the native ecosystem properties and processes are undisputed. Because of this, sometimes IPS is referred to as biological pollution or green cancer (IUCN/SSC, 2002).

The wide range of habitats and environmental conditions makes Nepal, especially vulnerably susceptible to the establishment of IS of peregrine inchoation. Potential IAS from most areas of the world may find opportune habitat somewhere in Nepal. In recent years IS have gained considerable notoriety as major threats to native species and ecosystem. There are166 different non-native IPS are found in both biologically rich areas as well as human dominated landscape such as forest, fallow land, grassland, croplands and wetlands. Among them, 21 are identified as problematic and categorized as high, medium, low and insignificant are 6, 3, 7, 5 respectively are risk invader (IUCN/SSC, 2000). Species like Lantana camera, Mikania micrantha, Chromolaena orodata, Leucaena leucocephala are IAS in Nepal and Mikania micrantha is assessed as one of the six high risks posed IAS. (Tiwari et al., 2005). Although it is estimated that only 1% of introduced species actually become invasive (Vitousek et al., 1987), the damage that an IS can inflict on native communities makes understanding the nature of invasions one of the most pressing ecological problems. There is a virtual relationship between species richness and carbon sequestration and the biological invasions can have profound effects on both the structure and function of forest ecosystems (Lowe at al., 2002).

Many of the invasive plants in Nepal are withal listed in the Invasive Species Specialist Group (ISSG, 2000) list of the world's worst IS (Lowe at al., 2002) and some of them are more prominent and notorious. Eupatorium odoratum, E. adenophorum, Lantana camara and Eichhornia crassipes were first introduced as ornamental plants and they are now well established and ascendant in forest, farmland, wetland and wasteland (Kunwar, 2003) and some intentionally introduce. Similarly, other IS are introduced with the objective of various reason latter on it becomes as an invasion. Majority of alien plant species in Nepal is confined to the lowlands below 2000m (Tiwari et al., 2005) .Mikania micrantha (Asteraceae) is a perennial, sprawling vine with a wide distribution in the Neotropics, which extends from Mexico to Argentina (Holmes, 1982). Within this native range it is restricted mostly to riparian habitats, typically occurring around the margins of rivers, lakes and marshy terrain and is infrequently invasive (Barreto & Evans, 1995).

According to Global Invasive Species Database (GISD), Mikania micrantha damages or kills other plants by cutting out the light and smothering them. It also competes for water and nutrients, but perhaps even more importantly, it is believed that the plant releases substances that inhibit the growth of other plants. Mikania micrantha weed has been nominated as among 100 of "world's worst" invader (Lowe at al., 2002) and it is one of the major IAS of many tropical moist forest regions of Asia including Nepal and is still invading new areas, such as Northern Australia.

Invasion create a greatest threat to biological diversity and they may alter hydrology, nutrient accumulation and carbon (C) sequestration on grassland (Polley et al., 1997). Terrestrial C sequestration is one of several proposed strategies to reduce the rate of carbon dioxide (CO_2) accumulation in the atmosphere. The total forest C storage in South Asia is about 33.301 gigatonnes (Gt). Out of which, around 10.004 Gt forest C store in India, 291 metric ton (Mt) is in Pakistan, 35 Mt is in Bangladesh, 676 Mt is in Bhutan and 900 Mt is in Nepal (Greatest source of terrestrial sink) and total C content in the world forest ecosystem is 638Gt of C (FAO, 2006). It is estimates that the world's forests store 289 Gt of C in their biomass alone. For the world as a whole, C stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the global forest area (FAO, 2010). About one third of the globe's terrestrial C, exclusive of that sequestrated in rock and sediments is sequestrated in standing forests, forest understorey plants, leaf and forest debris, and in forest soils. Trees, both in above and below ground biomass, continue to accumulate C until they reach maturity; at that point about half of the average tree dry weight will be C (UNH, 2008). Soil C is an important part of the terrestrial C pool. However, soil is deteriorating at an alarming rate in developing countries like Nepal due to land use changes lowering C sequestration (IPCC, 2000). It is evident that the role of forest in climate change mitigation is significant, and that the C dynamic of the forest need to be taken into account in mitigation efforts. Understanding the effects of IS on C pools in live biomass represents a first crucial step towards identifying the potential impacts that biological invasions, and, have on C cycling (Litton et al., 2006).

IS may alter the atmospheric composition by changing rates of C-sequestration, or the emission of volatile organic carbon (OC) compounds and other biologically important gases. Gamba grass in tropical savannas of northern Australia increases large tree mortality having diameter at breast height (Dbh) 40.35 and nearly eliminates small with 0.10m Dbh tress (Cook et al., 2005). This results in a 2-25% decline in live trees C by single fires in addition to the non-biological oxidization and loss of C. In contrast, C sequestration of non-invaded woodlands in neighboring Queensland over 14 years was 0.37t/ha/yr, a 9% gain in live trees C with the ongoing increase in species invasion globally, there is an urgent need to broaden our horizon and determine the biotic and abiotic process regulating the impacts of biological invasion on ecosystem C sequestration (Burrows et al., 2002). Studies of IS introductions in the past revealed that the impacts of their invasion are complex and can permanently alter the structure and function of communities, cause local extinctions and changes in ecosystem processes. Although the increasing distribution and abundance of IPS globally is well documented, there are surprisingly few studies specifically addressing the long-term consequences for C sequestration (Ostertag et al., 2009; Strayer et al., 2006). Thus, this study endeavours to provide insight into the impact of IS in C sequestration.

2. Materials and Methods

2.1. Study Area

Our research conducted on Parsa Wildlife Reserve (PWR), which was gazetted in 1984 with the aim of preserving of an Asian wild elephant. The Reserve includes tropical and sub-tropical forests of Churia (Siwalik) and Bhabar physiographies regions from

Parsa, Makwanpur and Bara districts. Geographically, the PWR is located within north latitude of 27o 15’ to 27o 33’ and east longitude of 84o 41’ to 84o 58’. Resent news from Department of National Parks and Wildlife Conservation, Ministry of Forests and Soil Conservation, Nepal Government the total area of PWR is 637.37 sq. Km. (DNPWC, 2016). May is the hottest when the mean maximum temperature reaches to 39.8o C while coolest month is January with the mean minimum temperature 5.80C. The annual precipitation (1720.51mm) is dominated by monsoon rain (83% precipitation occurring between June to October) with modest winter rain. The relative humidity varies from 49.7% to 94.2%. Sal (Shorea robusta Gaertn. f.) is a dominant tree species of the PWR. The types of soil found in and around PWR are brown shallow soil, brown black, red soil, black soil, and brown soil.

The study area of this research was conduct on Shree Rotomate Deurali Buffer Zone Community Forest (SRDBZCF). SRDBZCF located on ward number 5 and 6. It was established in 2009/November/9. The total user household of this buffer user community while established was 149.The study area comprises various habitat types such as grassland, riverine forest, wetlands and afforested land. Total area of forest is 66.938 hectares and most of the forest is invaded by Mikania micrantha During inventory of SRDBZCF for fulfilment of above objective 1% intensity for sample plot were taken into consideration.

2.2. Data Collection

2.2.1. Sampling Design

The condition of Mikania micrantha in forest was estimated via the focus group discussion, key person interview and preliminary survey. Systematic random sampling was done to analyze the situation and condition of forest so that it can represent variety of coverage by Mikania macrantha i.e. low, medium and high. A concentric circular plot of 250 m2 (8.92 m radius) for tree and pole, where all the trees and poles greater than 5 cm Dbh were measured. Similarly, 100 m2 (5.64 m radius) for sapling and measured all the sapling greater than 1 cm and less than 5 cm Dbh. Likewise, 3.14 m2 (1m radius) for seedling; and 1 m2 (0.56 m radius) for litter, herbs and grasses were laid out simultaneously (Tiwari et al., 2005; ANSAB, 2011; MacDicken, 1997; IPCC, 2006; Walkey & Black, 1934; Chave et al., 2005). A total of 30 plots were chosen throughout the study site representing a variety of cover densities of Mikania micrantha. As a result, 10 plots were taken for low severity, 10 for medium severity and 10 for high severity. 1% sampling intensity was adopted for collection of plant biomass, forest inventory and soil sample collection (MoFSC, 2011).

2.2.2. Population Structure

For this study, population structure was measure based on Dbh class, basal area and density. For analysis of population structure, size class frequency and basal area distribution were constructed for low, medium and high severity area for tree by Dbh data less than 5 cm, count of seedling and sapling(diameter >1cm <5 cm). The basic parameters like Dbh class, basal area and density were measured in order to observe preliminary trend of severity in study site. These parameters were further used in analysis of C sequestration.

Sampling design was used to collect data for plant biomass, species diversity, regeneration density and soil sample collection. Due to sufficient length & countless number of branches, climbing, creeping and highly spreading nature of Mikania micrantha and also entangled form of its associate climbers: the actual discrete number of all climber could not be assessed and indirect method as number of invaded tree and climber species found in tree were considered to be the number of plants and species accordingly (Tiwari et al., 2005). Additionally, severity of invasion was calculated using following formula.

$$Severity = \frac{\frac{Total\ affected\ area\ of\ tree\ \&\ sapling}{Total\ basal\ area\ of\ tree\ \&\ sapling}}{\frac{Total\ no.of\ tree, seedling\ \&\ sapling}{Total\ no.of\ tree, seedling\ \&\ sapling\ affected}}$$

This method was modified with inclusion of affected basal area which provides better understanding on severity in various form of vegetation growth based on basal area including number of species. Invasion ability of Mikania micrantha on individual plant was ranked in 3 categories depending on percentage of smothering by the weed. Following criteria were considered for the ranking: low invasion (0-33%), medium 33-63% and high above 63% (Tiwari et al., 2005).

2.2.3. Sample Plot Measurement

Dbh of each tree within each plot was measured using diameter tape (D- tape) and height of each tree was estimated using Sunto Clinometer and Abney’s level. For woody shrubs, diameter was measured at 15 cm above the ground level. All bushes, grasses and herbaceous plants was clipped from the bottom and the fresh weight of the samples was measured and representative sample of 200gm both woody and herbaceous vegetation was taken to lab for oven dry and for further analysis. In addition, leaf litters and twigs within the plot of 1m *1m was collected separately weight and was taken to laboratory for oven dry.

2.2.4. Soil Organic Carbon (SOC)

Soil samples were taken, one from each of the sample plot so that it represent whole forest that may cover low, medium and high severity area. Soil samples were collected from three different depths 0-0.2, 0.21-0.40 and 0.41-0.60 m with the help of metal soil corer (4.8cm diameter and 10 cm long) of known volume. All material collected in the cores soil sample was placed into appropriately labeled sample bags for determining concentrations of OC and bulk density in the laboratory.

2.2.5. Secondary Data Collection

Secondary data necessary to fulfill the objectives of the study was collected from the concerned literature, libraries, Parsa Wildlife Reserve Office, District Forest Office, Buffer Zone Community Forest User Group and Non-Governmental Organization/International Non-Governmental Organization.

2.3. Data Analysis

2.3.1. Biomass Estimation

Biomass of tree includes stem, branch, leaves, root and undergrowth biomass. Biomass of big trees is difficult to measure so some of the important character like diameter and height was measure and biomass was predicted using model.

2.3.2. Above- Ground Tree Biomass (AGTB)

On the basia of climate and forest stand types the value of AGTB was obtained by using algometric equations (Chave et al., 2005) and is calculated as follows.

$$\mathrm{AGTB} = 0.0509 * \mathrm{pD}^2\mathrm{H}$$

Where,
AGTB = above-ground tree biomass [kg],
p = wood specific gravity [g/cc],
D = tree diameter at breast height [cm] and
H= tree height [m]

2.3.3. Above-Ground Sapling Biomass (AGSB)

The biomass values of saplings include foliage, branch, and stem compartments. The following regression model was used for an assortment of species to calculate biomass (ANSAB, 2011).

$$\log(\mathrm{AGSB}) = a + b\log(\mathrm{D})$$

Where,
log = natural log [dimensionless],
AGSB = above-ground sapling biomass [kg],
a= intercept of allometric relationship for saplings [dimensionless],
b= slope allometric relationship for saplings [dimensionless] and
D = over bark diameter at breast height (measured at 1.3 m above ground)

2.3.4. Litter, Herb, and Grass (LHG) Biomass

The biomass of LHG per unit area was calculated by using Good Practice Guidance developed by IPCC (2006).

$$LHG = \frac{W_{field}}{A} * \frac{W_{subsample,dry}}{W_{subsample,wet}} * \frac{1}{10000}$$

Where,
LGH= biomass of leaf litter, herbs, and grass [t ha-1],

Wfield = weight of the fresh field sample of leaf litter, herbs, and grass, destructively sampled within an area of size A [g],
A= size of the area in which leaf litter, herbs, and grass were collected [ha]
Wsubsample,dry = weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g]; and
Wsubsample,wet = weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g].

2.3.5. Below Ground Biomass (BGB)

BGB (the root biomass) was calculated by using root shoot ratio 12.5% (Mac Dicken, 1997).

2.3.6. Soil Organic Carbon (SOC)

Soil bulk density was determined by core sampling methods (MacDicken, 1997). The bulk density of the soil is different in different layers of the soil. Similarly, the C content in the soil also differs according to its layer and determined by Walkey-Black method (Walkey & Black, 1934). The following formula was used to calculate SOC and Bulk Density of the soil (Pearson et al., 2007).

$$\text{Bulk Density}(g/cc) = \frac{\text{Oven dry weight of soil}}{\text{Volume of soil in the core}}$$

For total soil C following formula was adopted

SOC (t /ha) = Organic Carbon Content % * Soil Bulk Density (kg/cc)*soil depth (m)

2. 3.7. Carbon Stock Calculation

There are two major pools of carbon stock - above ground biomass carbon and below ground carbon. The biomass was converted into carbon by using the conversion factor 0.47 (MoFSC, 2011; IPCC, 2006).

Total above ground carbon = C (AGTB) + C (AGSB) + C (LHG)

Total below ground carbon = C (BGB) + SOC

Total carbon content C (LU) = C(AGTB) + C (AGSB) + C (BGB) + C (LHS) + SOC

Where,
C (LU) = carbon stock density for a land-use category [Mg C ha-1]
C (AGTB) = carbon in above-ground tree biomass [Mg C ha-1] =AGTB*0.47
C (AGSB) = carbon in above-ground sapling biomass [Mg C ha-1] =AGSB*0.47
C (BGB) = carbon in below-ground biomass [Mg C ha-1] =BGB*0.47
C (LHG) = carbon in litter, herb & grass [Mg C ha-1] =LHG*0.47
SOC= soil organic carbon [Mg C ha-1]

2.4. Statistical analysis

Non parametric Chi-square test of goodness fit was used to test whether density per ha in each severity class area disturbed uniformly or not at 5% level of significant. Parametric F- test which is based on one way ANOVA was used to test whether average biomass and C per ha for each severity differ significantly or not at 10% level of significance. Posthoc test for differences between sites were performed with Tukey's honestly significant difference (HSD) method. Similarly Parametric F-test based on two way ANOVAs was used to test whether SOC differ according soil depth and severity level. The variability of soil, biomass OC regarding severity level in term of range, standard error of mean(SE) and Coefficient of variation along with ANOVA and Chi-square. The trend of population structure was analyzed only through simple calculation of density and basal area in term of diameter class. ANOVA was used to test whether basal area per plot differ significantly or not at 10% level significant. Micro soft Excel was used for initial database preparation and simple modeling. Further statistical analysis was carried out using SPSS 16 version.

3. Results

3.1. Vegetation diversity and properties of forest

For these analyses, Severity level was grouped into three categories (low: 0–30%, medium 30- 63% and more than 63%) on the basis of number of tree and sapling and basal area of the tree and sapling cover by Mikania micrantha. The number of tree per hectare was 380, 299, and 215 in low, medium and high area respectively (Table 1). It was reported that number of tree per hectare in low invasion was 1.27 times higher than medium. Similarly, medium invasion was 1.39 times higher than high invasion area. The mean diameter of the stand was high in low severity area and similarly large tree was observed in term of Dbh 68cm and height 33.1m in low severity area. The mean Dbh and height of tree in low invasion area was 29.1cm and 13.1m respectively where medium was 23.9cm and 12.2cm respectively and in high area was 26.1 and 13 respectively as shown in Table 1.

Table1. Summary statistics of forest tree.

Severity	No. of Stem/ha	Dbh			HT		
		Mean	Max	Min	Mean	Max	Min
Low	380	29.1	68	9	13.1	33.1	5.9
Medium	299	23.9	49	8	12.2	29.3	3
High	215	26.1	40	7	13	22	2.1

ha, hector; Dbh, Diameter at breast height; HT, Height.

Table 2, describes the overview of saplings condition in low, medium and high severity area. From the field survey, the number of sapling per hectare was 365, 380, and 343 in low, medium and high area respectively. It was reported that number of tree per hectare in low invasion was 0.96 times lower than medium. Similarly, the mean Dbh and height of sapling in low invasion area was 2.2cm and 2.5m respectively where medium was 3.9cm and 9.5m respectively and in high area was 4.2cm and 8.2m respectively as shown in Table 2.

Table2. Statistics description of Sapling.

Severity	No. of Stem/ha	Dbh			HT		
		Mean	Max	Min	Mean	Max	Min
Low	365	2.2	5	1	2.5	7	1
Medium	380	3.9	5	1.5	3.8	9.5	1

High	343	4.2	5	1	4.4	8.2	1

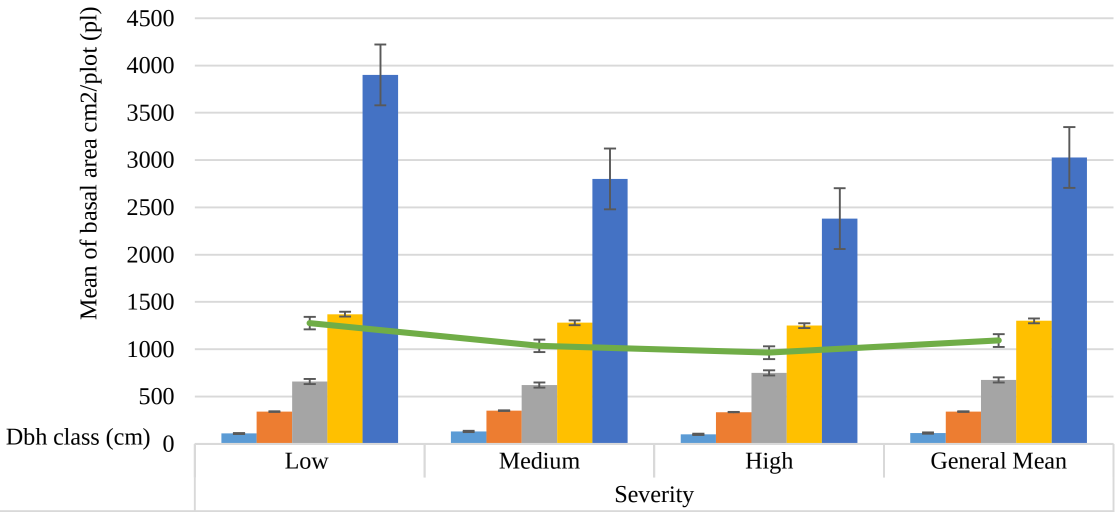
ha, hector; Dbh, Diameter at breast height; HT, Height

3.2. Population structure

3.2.1. Tree

3.2.1.1. Basal area

Stand in low, medium and high severity area were different in basal area which accounts for higher in low medium in comparison to other severity level (Figure 1). The mean basal area of medium severity was 1.9 and 1.29 times higher than low and high severity area. The higher basal (130.3 cm2/pl) area in 5-15cm diameter was found in medium and low in higher severity area. Similar higher basal area was observed in medium severity (350.2 cm2/pl) and followed by low (340.4 cm2/pl) and higher severity (335.5 cm2/pl) were found in15-25cm diameters. Basal area containing diameter 25-35 class was found higher in (750.1 cm2/pl) higher severity and followed by low and low in medium severity. Basal areas of remaining diameter were found high in low severity and low in high severity (Figure 2). The basal area of low was observed high as compared to two remaining severity area. ANOVA analysis revealed that there was no significant difference in basal areas of different severity level except for diameter class of 25-35cm, i.e. between high and low; and high and medium severity.

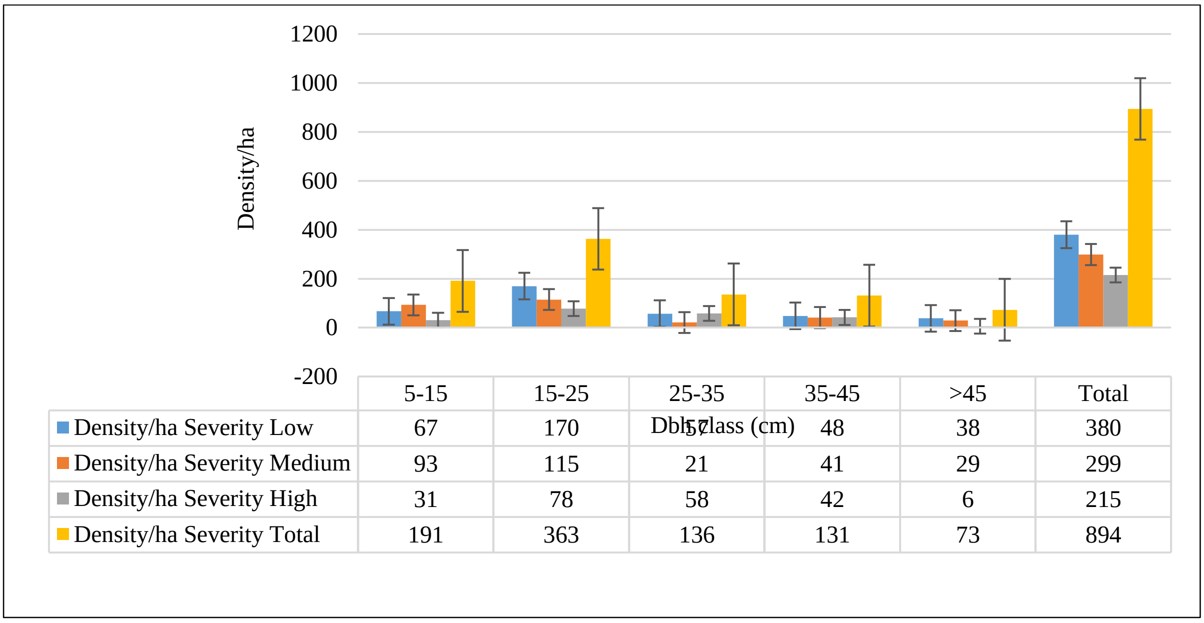


Dbh class (cm)	Low	Medium	High	General Mean
5-15	109.2	130.3	100.8	113.4333333
15-25	340.4	350.2	335.5	342.0333333
25-35	660.2	620.7	750.1	677
35-45	1370.9	1280.1	1250.3	1300.433333
>45	3900.7	2800.6	2380.4	3027.233333
General mean	1276.28	1036.38	963.42	1092.026667

Figure1. Diameter distribution on the basis of basal area at different severity level.

3.2.1.2. Tree density

Diameter distribution pattern on the basis of severity level is described in fig. 3. The total stem density was higher (380/ha) in low severity area followed by medium (299/ha) and low (215/ha) in higher severity area (Table 1). The higher number of tree (93/ha) was found in 5-15cm diameter class followed by (67/ha) as low and (31 /ha) higher severity area respectively. Similarly, higher number was observed in low severity (170/ha) in 15-25 diameters and followed by medium (115/ ha) and low (78/ha) in higher severity. Tree density containing diameter 25-35cm class was found higher in (58/ha) in both high and low severity and least in medium (21/ ha). Tree density with diameter of 35-45cm was found higher (48/ha) in low severity and lower (41/ha) in medium and (42/ha) higher severity (Figure 2). Similar trends was found in the diameter >45 as in 15-25cm diameter class.



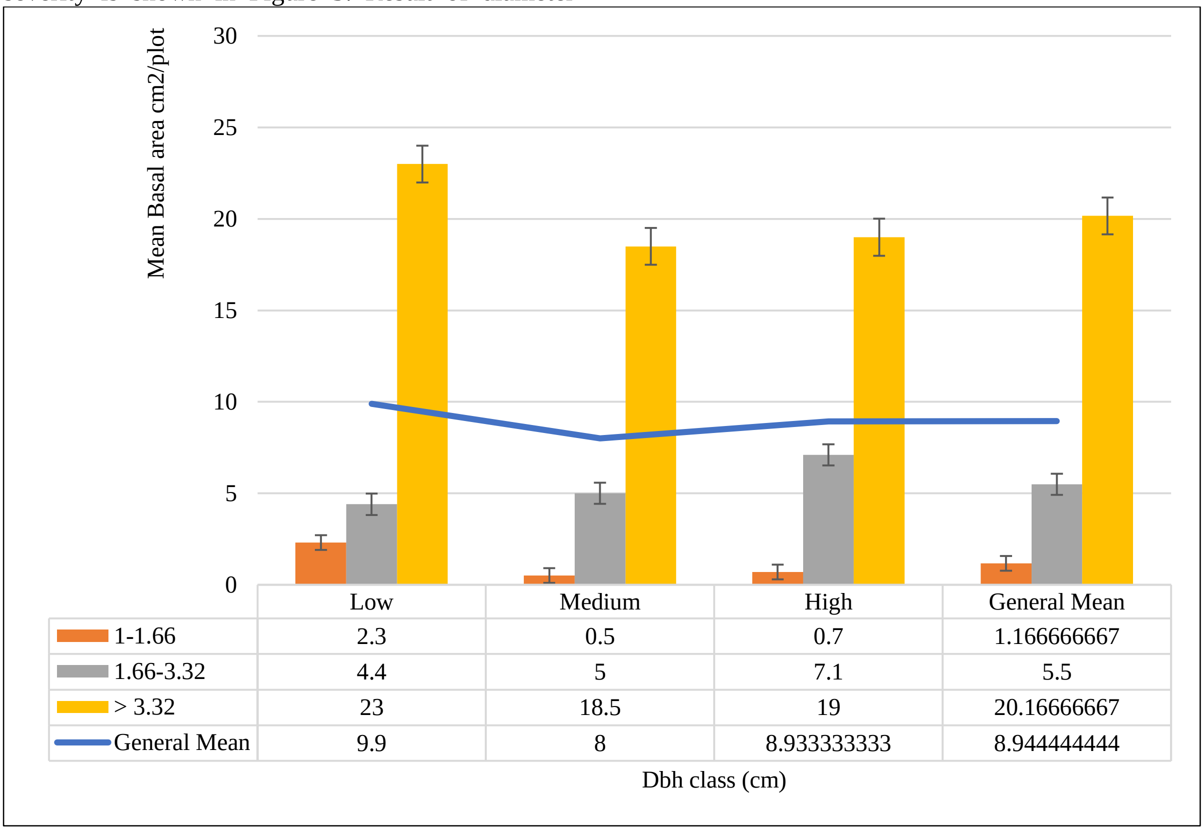
	5-15	15-25	25-35	35-45	>45	Total
Density/ha Severity Low	67	170	57	48	38	380
Density/ha Severity Medium	93	115	21	41	29	299
Density/ha Severity High	31	78	58	42	6	215
Density/ha Severity Total	191	363	136	131	73	894

Figure2. Size class frequency distribution of tree at different severity level of forest.

3.2.2. Sapling

3.2.2.1. Basal area

Diameter distribution pattern in different level of severity is shown in Figure 3. Result of diameter class distribution showed that low severity has higher basal area followed by higher and medium severity area respectively (Figure 3).



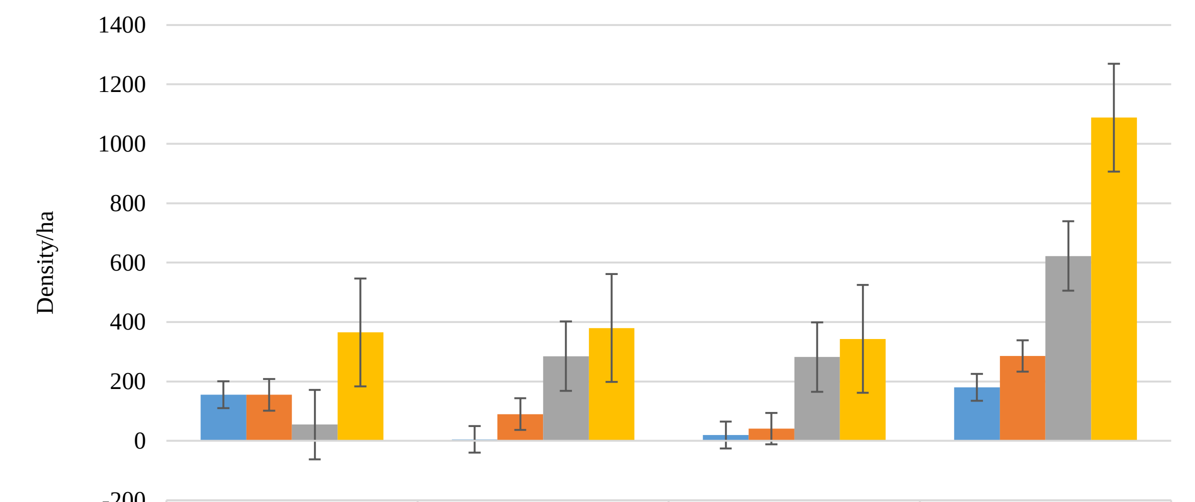
	Low	Medium	High	General Mean
1-1.66	2.3	0.5	0.7	1.166666667
1.66-3.32	4.4	5	7.1	5.5
> 3.32	23	18.5	19	20.16666667
General Mean	9.9	8	8.933333333	8.944444444

Figure3. Distribution of basal area by diameter class at different severity level.

In diameter class 1-1.66cm it was found that higher in low severity area followed by high and medium i.e. 2.3cm2/plot, 0.7 cm2/plot and 0.5 cm2/plot respectively. Diameter class of 1.66-3.32cm, the basal area was found high in high severity and low in lower severity. Remaining diameter class (3.32-5cm) was found highest in low severity followed by high and low in medium severity area. 45% of the plot completely lacked individuals in the sapling category. There was no significant difference in basal areas of different severity level except for diameter class of 1.66-3.32 cm, i.e. between high and low; and high and medium severity.

3.2.2.2. Density of sapling (number per hectare)

Diameter distribution pattern on the basis of severity level is described in Figure 4. The total sapling density was higher in medium severity area followed by medium in low severity and low in higher severity area. Diameter class of 1-1.66cm containing density of 155/ha, 5/ha and 20/ha in low, medium and high severity area respectively. Similarly, higher density was found in medium severity and higher severity and low in low severity area in the diameter class >3.32. Remaining Diameter 1.66-3.32cm higher density was observed in low, medium and high severity area respectively.



	Low	Medium	High	Grand Total
1-1.66	155	5	20	180
1.66-3.32	155	90	41	286
> 3.32	55	285	282	622
Total	365	380	343	1088

Figure4. Size class frequency distribution of sapling at different severity level of forest.

3.3. Above ground biomass (AGB) estimation

The biomass of tree varies in different plots within and between low, medium and high severity area of the forest because of variation in tree size as well as tree density. In Table 3, above ground tree biomass (AGTB) was found higher in low invasion area (192.22±48.18 t/ha) followed by medium severity (161.21±32.15 t/ha) and low (85.35±15.33 t/ha) in higher severity area. In this study there was no significant difference between AGTB in different severity level ($p>0.1$). Above ground sapling biomass (AGSB) was higher in low (3.52±1.2 t/ha), followed by high (2.1±0.23 t/ha) and low (0.99±0.21 t/ha) in medium severity area. AGSB of severity low and medium are significantly different ($p>0.1$). Leaf litter, grass, seedling (LGS) biomass was higher in medium invasion area and followed by high and then low invasion area respectively (Table 3). No significant difference was found in LGS ($p>0.05$). Total above ground biomass (AGB) was higher in low invasion area (195.83 t/ha), followed by medium (162.42 t/ha) and higher severity area (87.63 t/ha). There was no significant difference in total AGB on the basis of severity level ($p>0.05$)

Table3. Distribution of Above ground biomass in different severity level.

Severity	AGTB (t/ha)			AGSB (t/ha)		LGS biomass		Total AGB	
	Mean	SE	Min	Max	Mean	SE	Mean	SE	Mean
Low	192.22	48.18	0.11	680.33	3.52	1.2	0.09	0	195.83
Medium	161.21	32.15	13.5	390.5	0.99	0.21	0.22	0.02	162.42
High	85.35	15.33	3.19	152.21	2.1	0.23	0.18	0.01	87.63
Mean	146.26	31.89			2.20	0.55	0.16	0.01	148.63

t/ha, tons per hector; SE, Standard error; AGTB, Above ground tree biomass; AGSB, Above ground sapling biomass; LGS, leaf litter, Grass, Seedling; AGB, above ground biomass.

3.4. Above ground carbon (AGC) sequestration

Above ground tree carbon (AGTC) sequestration was high (116.20±20.2 t/ha) in low severity area compared to other severity (Tab. 1). AGTC sequestration did not differ between low, medium and high severity area (p>0.05). Above ground sapling carbon (AGSC) sequestration (Table 4) was high in low severity (2±0.50 t/ha) followed by high severity (0.56±0.13 t/ha) and medium (0.55±0.11 t/ha) severity respectively. There was no significant difference between severity level and AGSC sequestration (p>0.1) but severity low and medium differ significantly.

Table4. Distribution of Above ground Carbon sequestration in different severity level.

Severity	AGTC sequestration(t/ha)				AGSC sequestration(t/ha)		LGS sequestration (t/ha)		Tota AGC (t/ha)	
	Mean	SE	Min	Max	Mean	SE	Mean	SE	Mean	SE
Low	116.9	20.2	17.6	320.1	2	0.50	0.0033	0.0026	113.24	21.1
Medium	76.9	13.5	6.07	189.3	0.55	0.11	0.009	0.011	75.19	14.5
High	43.12	5.06	1.95	77.54	0.56	0.13	0.01	0.01	47.15	13.2
Mean	78.96	12.9			1.037	0.25	0.0074	0.0079	78.53	16.3

t/ha, tons per hector; SE, Standard error; AGTC, Above ground tree carbon; AGSC, Above ground sapling carbon; LGS, Leaf litter, grass, seedling; AGC, Above ground carbon.

LGS carbon sequestration was higher in high (0.01±0.01 t/ha), medium in medium (0.009±0.011t/ha) and lesser in low severity area (0.0033±0.0026 t/ha) (Table 4). No significant difference between carbon sequestration of leaf litter was observed according to severity measure (p>0.1). Similarly total above ground carbon (AGC) sequestration in low severity was high (113.24±21.1 t/ha) followed by medium (75.19±14.5 t/ha) and low in (47.15±13.2 t/ha) higher severity.

3.5.1. Tree Root biomass and carbon sequestration

Root Biomass was high in low severity area (48.21±8.92 t/ha) followed by medium (36.24±6.18 t/ha) and low in higher severity area (21.16±2.99 t/ha). Similarly, root carbon sequestration was found high in (25.64±4.23 t/ha) low severity as compared to higher severity area (9.56±1.13 t/ha) (Table 5). There was no significant difference between root biomass and carbon of tree in the severity level (p>0.05).

3.5. Root biomass and carbon sequestration

Table5. Tree root biomass and carbon sequestration at different severity level.

Severity	Root biomass (t/ha)				Carbon by root (t/ha)			
	Mean	SE	Min	Max	Mean	SE	Min	Max
Low	48.21	8.92	0.12	143.12	25.64	4.23	4.12	71.03
Medium	36.24	6.18	2.96	83.81	15.32	2.12	1.89	42.15

High	21.16	2.99	0.79	33.25	9.56	1.13	0.58	16.72
Mean	35.20	6.03			16.84	2.49		

t/ha, tons per hector; SE, Standard error.

3.5.2. Sapling Root biomass and carbon sequestration

Table 6, clearly showed that Root Biomass was high in low severity area (0.51±0.19 t/ha) followed by high (0.25±0.04 t/ha) and low in medium severity area (0.16±0.04 t/ha). Similarly root carbon sequestration was found high in low severity (0.29±0.10 t/ha) and least in medium severity area (0.11±0.02 t/ha) (Table 6). There was significant difference between low and medium severity of carbon and biomass (p>0.1).

Table6. Sapling Root biomass and carbon sequestration at different severity level.

Carbon by root (t/ha)								
Severity	Mean	SE	Min	Max	Mean	SE	Min	Max
Low	0.51	0.19	0.08	1.35	0.29	0.10	0.03	0.7
Medium	0.16	0.04	0	0.46	0.11	0.02	0.02	0.19
High	0.25	0.04	0.7	0.19	0.13	0.31	0	6.51
Mean	0.307	0.09			0.177	0.143		

t/ha, tons per hector; SE, Standard error.

Higher number of sapling was found in higher severity area and mean Dbh of sapling was found in medium severity (Table 2). Although higher number of sapling and mean Dbh was not found in low severity area comparison to both sites, while calculating the biomass both factors were considered, so higher biomass and carbon was represented by lower severity area.

3.6. Soil carbon sequestration

3.6.1. Soil Bulk Density

The minimum BD (2.71±0.32 t/ ha) was found at the top soil (0-20 cm) and maximum BD was in (2.80±0.36 t/ha) at the depth of 40-60 cm in low severity area. Similarly, minimum BD (2.53±0.35 t/ha) at the depth of 0-20 cm in medium severity area while maximum BD (2.68±0.41t/ha) was found at the depth of 40-60 cm. In high severity area the minimum BD is found in the depth of 0-20cm and higher in the depth of 40-60 cm. There was variation in the bulk density (BD) with respect to depth in the forest soil.

Table7. Bulk density (t/ha) in different severity.

Bulk Density (t/ha) Severity						
Soil	Low	Medium			High	
	Mean	SE	Mean	SE	Mean	SE
0-20	2.71	0.32	2.53	0.35	2.27	0.72
20-40	2.69	0.35	2.8	0.85	2.8	0.34
40-60	2.80	0.36	2.68	0.41	2.58	0.4

t/ha, tons per hector; SE, Standard error.

3.6.2. Soil organic carbon (SOC)

Soil organic carbon (SOC) depends upon various biotic and abiotic factors, such as microclimate, faunal diversity, land use and management. The C content in the soil is generally decreased with respect to increasing soil depth. The maximum SOC (36.65±4.12) was found in topsoil and minimum SOC in reported in 40-60cm depth. The maximum SOC was found in the depth of 0-20 cm and minimum in 40-60cm in all severity level (Table 8). There is remarkable variation in the SOC with respect to soil depth but converse in the case of severity. SOC in each layer of the soil were significantly different (P>0.05). As the depth increases SOC was increases. There was insignificant difference between SOC and level of severity (P>0.05%).

Table8. Soil organic carbon at different severity level.

Severity								
SOC(t/ha)	**Low**		**Medium**		**High**		**Total Carbon of soil (t/ha)**	
Soil Depth (cm)	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
0-20	**25.21**	**2.31**	**33.71**	**3.96**	**44.25**	**4.02**	**36.65**	**4.12**
20-40	**15.29**	**2**	**19.05**	**3**	**19.96**	**3**	**18.11**	**2.29**
40-60	**13.54**	**1.98**	**12.14**	**3.17**	**12.14**	**1.67**	**12.14**	**2.61**

SOC, Soil organic carbon; t/ha, tons per hector; SE, Standard error.

3.7. Total carbon Sequestration in low, medium and high severity area

Total carbon sequestration in low severity area was found high in 196.87 t/ha followed by medium and then higher severity area (Table 9). The soil carbon of higher severity was higher in comparison to other two severities (Table 9).

Table9. Total carbon sequestration at different severity level of forest.

		Severity		
Level	**Level Categorization**	**Low**	**Medium**	**High**
AGC (t/ha)	**Above ground biomass OC**	**116.9**	**76.9**	**43.12**
BGC (t/ha)	**Root carbon of tree**	**25.64**	**15.32**	**9.56**
	Root carbon of sapling	**0.29**	**0.11**	**0.13**
	Soil carbon	**54.04**	**64.9**	**76.35**
Total		**196.87**	**157.23**	**129.16**
Mean		**161.09**		

AGC, Above ground carbon; BGC, Below ground carbon; t/ha, tons per hector; OC, Organic Carbon.

3.8. Carbon sequestration by Shree Rotomate Deurali Buffer Zone Community Forest (SRDBZCF).

The total carbon stock of SRDBZCF was 161.09 ton per hectare. Result found that above ground biomass contribute by 78.97 t/ha of carbon and sapling root by 0.177 t/ha. Similarly Above ground total root found 16.84 t/ha and soil 65.097 t/ha of carbon (Table 10).

Table10. Total carbon sequestration in Shree Rotomate Deurali Buffer Zone Community Forest.

Carbon sequestration(t/ha) level in different component of forest	**Carbon(t/ha)**
Soil C	**65.097**
AGC	**78.97**
AGTRC	**16.84**
AGSRC	**0.177**
Total Carbon	**161.09**

t/ha, tons per hector; C, Carbon; AGC, Above ground Carbon; AGTRC, Above ground tree root carbon; AGSRC, Above ground sapling root carbon.

4. Discussion

Thus this study endeavors to provide insight into the impact of invasive species (IS) in C sequestration and trend in forest structure. Although the increasing distribution and abundance of invasive plant species (IPS) globally is well documented, there are surprisingly few studies specifically addressing the long-term consequences for C sequestration (Ostertag et al., 2009; Strayer et al., 2006). With the ongoing increase in invasion species (IS) globally, there is an urgent need to broaden our horizon and determine the impacts of biological invasion on ecosystem C sequestration.

Tiwari et al. (2005) modified the method with inclusion of affected basal area which provides better understanding on severity in various form of vegetation growth based on basal area including number of species. Invasion ability of Mikania micrantha on individual plant was ranked in 3 categories depending on percentage of smothering by the weed. Following criteria were considered for the ranking: low invasion (0-33%), medium 33-63% and high above 63%. Previous studied about effect of invasive alien species (IAS) in tropical riverine forest conducted in Kumrose Buffer Zone community forest (KBZCF) of Chitwan, which is very close to the study area, found similar result. According to her, mean diameter in invaded and non-invaded area was 41cm and 47.7cm respectively (Ulak, 2010). However, a study by Litton et al. (2006) in Hawaiian island which has drier ecosystem and is much different bioclimate than the study area also reported the similar trend of impact on stem density (trees/ha), which was found higher in native site than invaded site.

Litton et al. (2006) found the basal area and total stem density higher in native site compared to invaded sites. He further estimated total basal area of Diospyros sandwicensis 86% and 78% in native and invaded forest respectively. Similar to Litton et al. (2006), our study also predicted higher basal area in low severity as compared to medium and high. This gives a trend of population structure in study site with low, medium and high severity. Litton et al. (2006) verified that there was 4 times higher stem density in the native forest rather than invaded area by IS, particularly the perennial bunchgrass Pennisetum Setaceum. While study of Ulak (2010) showed tree density in KBZCF at Chitwan was found higher in non-invaded area than invaded area. Similar conclusion was drawn by my study that number of tree per hectare was 1.8 times higher in lower severity compared to higher.

There was no significant difference in basal areas of different severity level except for diameter class of 1.66-3.32 cm, i.e. between high and low; and high and medium severity. Previous study found similar result that basal area of invaded sites was lower than native sites and also reported that in the invaded forest both species exhibited a complete lack of sapling and small size individual whereas in native site a diverse array of seedling, sapling and individuals in all size classes were found (Litton et al., 2006).This study also provides similar insights since not all size class are equally represented in all the severity level. The recruitment of seedling to sapling – a transition period in which plants are competing greatly with IS like P. setaceum for limiting resources such as water, minerals and light (Cabin et al., 2002). Once regeneration established to sapling, there may be no impact to them because impact of IS directly related to community structure, diversity, ecosystem process and competition (Vilà M et al., 2011).

Litton et al. (2006) found similar result and manifested that above ground tree biomass may be different in native (108.9 Mg/ha) and invaded forest (112.1 Mg/ha) and due to preponderance of wood biomass in large Diospyros sandwicensis trees at both sites. They further reported that Grass invaded forest had more understory biomass than the native forest, but no differences were observed in total aboveground live biomass (tree + understory) between native (108.9 Mg ha 1) and invaded forests (112.1 Mg/ ha). However, total aboveground live biomass was 93% lower at the converted site (7.8 Mg /ha), which is the eventual fate of invaded forests with no natural regeneration of native canopy. Ulak (2010) has also interpreted in KBZCF that above ground biomass was higher in invaded area than non-invaded area. Similarly, others researcher also observed fresh and dry biomass of species per square meter in the invaded areas also reduced drastically when compared with the non-invaded area (Dogra et al., 2009a). Invasion of perennial sage brush communities by annual grasses and resulting wildfires reduced integrated daily net carbon exchange in the Intermountain West (Prater & DeLucia, 2006). Some research also indicated that invasive grasses in seasonally dry, submontane forests of Hawaii reduced native shrub, but not tree, diameter increment (D'Antonio & Vitousek, 1992). The invasion of Hawaiian tropical dry forests by a non-native perennial bunchgrass, and subsequent conversion to grassland, substantially reduced the aboveground carbon sink strength of these systems. However, the conversion of these forests to grasslands reduced aboveground live biomass (Litton et al., 2006; Jaramillo et al., 2003; Bonino, 2006). Litton et al. (2006) also demonstrated that the presence of grass in the under story of an intact tree canopy, by itself, did not significantly change carbon pools in Aboveground biomass. Similarly, in our study site a comparative difference in above ground tree biomass was seen but not significantly in the study site. However in case of sapling, significant sapling biomass was observed. This may be due to higher sapling size in term of diameter in higher severity area and higher number per hectare was found in medium severity area however on an average in terms of diameter and number of tree per hectare cumulatively biomass was seen higher in low severity. Comparatively, a higher biomass of sapling was observed in two severities than high severity area. Litton et al. (2006) reported that there were no sapling and few small diameter individuals in invaded forest. In case of leaf biomass his study concluded that total leaf biomass was higher in invaded area in comparison to Native area. However in our study, leaf litter was comparatively higher in high severity area as compared to low severity. This is due to considerable input of leaf biomass of Mikania micrantha.

Correspondingly, Ulak (2010) studied similar trends were manifested by total above ground carbon sequestration. Litton et al. (2006) also demonstrated higher carbon in native compared to grassland and invaded sites. This is due to obvious reason since the trend is shown by biomass and carbon sequestration is estimated based on biomass.

According to Litton et al. (2006), a complete understanding of the effects of IS on carbon pools should also take belowground dynamics into account. In our study root biomass was high in low severity area followed by medium and low in higher severity area. Similarly, root carbon sequestration was found high in low severity as compared to higher severity area. This was relatively similar to Litton et al. (2006) and Ulak (2010) finding. It clearly indicated that there was no significant difference between root biomass and carbon of tree in the severity level.

The bulk density of soil depends greatly on the mineral make up of soil and the degree of compaction. The bulk density of soil is inversely related to the porosity of the same soil: the more pore space in a soil the lower the value for bulk density. Similar research found the measurements of SOC pools (0-30 cm) showed larger pools under P. arundinaceous invasion herbaceous (Bills, 2008). Ulak (2010) study also showed similar trend of higher SOC in invaded area. Since Leaf litter and root litter inputs play major role in forest SOC dynamics (Shrestha & Singh 2008), Mikania micrantha also surplus the soil with additional biomass which contributes for higher soil carbon in high severity sites. The comparison of SOC between low, medium and high severity area showed a difference.

Research found similar trend of result in case of total above ground live biomass in a tropical dry forest of Hawaii (Litton et al. 2006). Ulak (2010) also interpreted that the soil carbon is higher in the invaded than non-invaded area. In invaded area there was carpeting of Mikania micrantha on the ground which increases the biomass of the undergrowth and was found root (Mikania micrantha) contained in the soil, consequently in higher carbon stock in the undergrowth and soil. This concludes concluded that Mikania micrantha alter the level of carbon in soil.

5. Conclusion

The invasive plant modifies the micro habitat changes physical environmental condition and even releases certain metabolites that make soil chemistry unsuitable for germination of other species. Deforestation is one of the factors that make the forest susceptible to invasion, consequently invasion further cause's degradation to the forest. However, still understanding about impact or contribution of invasion on carbon emission remains preliminary.

Population structure in SRDBZCF riverine mixed forest of Terai region of Nepal showed a considerable effect of invasion on regeneration as compared to sapling and tree species and shows the probable trend of change in future forest structure. Even the forest structure in terms of basal area and density was in better condition in low severity area than in higher. The invasion of alien species like Mikania micrantha is jeopardizing the forest condition and compromising forest productivity of Terai forest by deteriorating forest.

Invasion of Mikania micrantha also marked an impacts on population structure and C sequestration of the ecosystem. IS creates unfavorable environment for growth of previously prevalent local species. The earlier stage of plant growth, especially regeneration, where plants lack robustness and are highly vulnerable, often fails in altered micro habitat created by aggressively colonizing invasive plants. Regeneration growth is highly impaired because of the carpeting nature of Mikania micrantha.

The total C stock of SRDBZCF was 161.09 t/ha. Result found that AGC contribute by 78.97 t/ha of C and AGSRC by 0.177 t/ha. Similarly root of tree and AGTRC was found 16.84 t/ha and soil C was 65.097 t/ha. The total biomass carbon sequestration in low severity area was found high followed by medium and the higher severity area. From this, we can conclude that the Mikania micrantha has also negatively affected on the carbon stock of the SRDBZCF in near future as seedling were affected by severity, although in present result did not vary in net (above and below ground) carbon .

Overall findings demonstrated that Mikania micrantha has negative effect on population structure, forest regeneration and carbon stock.

6. Acknowledgement

The authors are grateful to all the staffs of the District Forest Office, Parsa Wildlife Reserve Office and National Trust for Nature Conservation, Parsa Conservation Project of Parsa district, Nepal for providing all possible help during the survey and to those ethnic people from Shree Rotomate Deurali Buffer Zone Community Forest user groups who have actively contributed in the field work of the study. The authors are also thankful to all the staffs of the Ministry of Forest and Soil Conservation and Department of National Parks & Wildlife Conservation, Kathmandu, Nepal for their continuous supervision, guidance, suggestions, support and encouragement throughout my research period. Authors are also thank full to Tribhuvan University, Institute of Forestry, Pokhara-15, Nepal for providing lab and library facility. We would like to express sincere thankfulness to Northwest A&F University, Shaanxi, China for providing us financial support for our study.

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