Patterns of invasion by crofton weed (Ageratina adenophora) in Kailash sacred landscape region of western Himalaya (India)

Chaudhary Alka, Adhikari B.S., Joshi N.C. and Rawat G.S.

Received: 07.08.2019   Revised: 09.10.2019    Accepted: 20.10.2019

Abstract

Invasion of alien species in high altitude ecosystems is a potent threat to the species diversity as well as it can cause severe environmental and economic issues. The invasion of alien plant species can be facilitated by many eco-climatic factors. The present study was conducted to assess patterns and trends of invasion by Ageratina adenophora in major land use and land cover types; in Gokerneshwergad watershed of Kailash Sacred Landscape (KSL) in western Himalaya. Extensive surveys were conducted to map the species in each season and habitat type. Sites with high biotic pressure and open forest canopy were the most suitable habitats for its growth. A negative correlation was found between distribution and altitude. The highest invasion was recorded in between 1700 – 1800m elevation gradient, between 20° and 30° slope positions and at North (33.33%), whereas, the lowest invasion was recorded between 700 – 800m in South-East directions (3.70%). Several other parameters such as distance from the disturbance site such as road, villages or settlements, drainage and soil texture were also found to be affecting the distribution pattern of this species. Interestingly results reveal that the alien plants also start competing among themselves after reaching their threshold level.

Key Words: Invasive alien species, watershed, Kailash Sacred Landscape, biodiversity, Himalaya

Introduction

Invasive alien species are those which become established in natural or semi-natural ecosystems or habitats, an agent of change and threaten native biological diversity (IUCN, Guidelines for the prevention of biodiversity loss caused by alien invasive species, 2000). Invasive plant species can cause important economic, environmental and social losses, either introduced deliberately or accidentally to different parts of the world (Anderson, 2005). Plant diversity around the world is facing various threats and is reducing very rapidly (Dogra et al., 2009). Local studies have shown that invasive plant species can directly or indirectly affect the food security of residents. In areas where they spread, invasive can destroy natural pasture, displace native trees, and reduce the grazing potential of rangelands (Admasu, 2008). After the habitat loss, the invasion of alien plant species has become the second-highest threat to plant diversity (Hobbs and Humphries, 1995) in the new regimes. It may be due to invasive species have many important adaptation techniques as compared to native plants as faster rates of growth and biomass production compared to native species, high reproductive efficiency including production of a large number of seeds, higher efficient dispersal, competitive ability, rapid establishment, vegetative reproduction, and several other factors that help them adapt to new habitats (Sharma et al., 2005; Simberloff et al., 2005) and broader range of tolerance (Walther et al., 2009; IUCN, 2013). Preventing or tackling biological invasions at a very early stage is considered as the most efficient and cost-effective approach (Brunel et al., 2013). This demand awareness of the threats they pose, preventive measures to stop new invasions and control of those species that have already invaded the ecosystems. Some of the widely spread and documented invasive plant species all over the world are Ageratina adenophora, Lantana camara, Parthenium hysterophorus and Bidens pilosa. Himalaya being the youngest mountains on earth are very well known for their vast biodiversity due to which they become one of the best sites for the study of climate change on the earth. It has been observed that species of higher elevations are projected to shift higher, due to which few invasive alien plant species which were earlier limited to the lower areas are now shifting towards the higher
altitudinal areas of Himalaya (Telwala et al., 2013). About 50% of the alien species are intentionally introduced in the Himalaya (Sekar and Manikandan, 2012) and others came through trade and gain imports. In India the studies on invasive plants and their invasions is still missing, except a few studies, mainly on the specific locations listing (Myers et al., 2000; Reddy, 2008; Singh et al., 2010; Sekar and Manikandan, 2012) ecological status (Jaryan and Singh, 2013; Sharma et al., 2012; Adhikari and Tiwary, 2015; Saxena, 1993; Bhatt et al., 1994; Negi and Hajra, 2007) comprehensive studies on invasive species and plant invasions are still missing except a few studies (Singh et al., 2008; Myers et al., 2000). Climate change may increase the opportunities for introduction and spread of alien invasive plants (Kriticos et al., 2010; IUCN, 2017). Despite the recognition of the impacts caused by invasive plants worldwide (Mooney and Hobbs, 2000), there are still many regions in the world where basic information on naturalized plant taxa and plant invasions is only superficial or completely lacking like Asia and neighbouring regions (Corlett, 1988; Enomoto, 1999). Therefore, an urgent need was felt to study implications of climate and environmental change on distribution and abundance of major invasive alien species in the Himalayan region along with the impact assessment and management of such species.

Study area
The study was carried out in Gokerneshwergad watershed, a part of Kailash Sacred Landscape (KSL) in Pithoragarh district of Uttarakhand state, India (Fig. 01). The topography of the study area is hilly with an interspersion of different type of forests, agricultural fields; fallow land ranging from 600 to 2200m. The climate is mild and generally warm. The summers have much more rainfall when compared with winter. The average temperature is 25 °C. The rainfall here averages 1263 mm. (USIDCL 2012). The total area of the watershed under study was calculated using Arc GIS and was found to be 31.93 Km².

Materials and method
Site selection was conducted based on the intensive reconnaissance survey of the Gokerneshwergad watershed depending on the availability of the alien plant species, i.e. Ageratina adenophora (Syn. Eupatorium adenophorum). Intensive field surveys were conducted during January to April 2016 to record the maximum patches of invasion by
Ageratina adenophora in adjoining areas of 20 villages in Gokerneshwer gad watershed covering forests, fallow lands, agricultural lands and grasslands. The invasion of Ageratina adenophora was also discussed with the local communities and based on the group discussions patches in each village were identified and classified based on the population intensity of selected species such as dense, moderate or sparse. Following the participatory mapping of species-specific, a rapid ecological assessment was carried out in 41 different patches. 229 random quadrates of 1x1m² were laid in the identified patches in the watershed. The number of individual of Ageratina adenophora and its clumps were recorded in each plot. The density of Ageratina adenophora was calculated following the method proposed by Misra (Misra, 1968).

Results and Discussion
Elevation, aspect, and slope are considered the three main topographic factors responsible for the distribution and patterns of vegetation in mountain areas (Titshall, O’Connor and Morris, 2000). Therefore, these topographic factors (aspect, elevation and slope) of the region were created from a digital elevation model. Euclidean distance from road and water source was prepared in Arc GIS-L1, and cover types, important geological layers such as soil textures were also prepared. Several other parameters such as distance from the disturbance site and watershed and land cover type were also found to be important that control the distribution and pattern of Ageratina adenophora. The results of the current study are illustrated as follows:

The area of invasion was least in Godiyagaon (485 m²) followed by Bhurumuni village (613 m²) whereas, the maximum invasion was recorded in Dhyuree (5370 m²). The maximum density of Ageratina adenophora was recorded in Jajroli (203/m²) followed by Mostmanu (230.83/m²), and the lowest value (62.25/m²) was recorded in Bhurumuni (Fig 2). Out of 41 patches surveyed; maximum patches were recorded in the boundaries of Bichcot, Jagtar and Naini villages (04) whereas, the lowest number of patches were recorded in Malliseem, Sinchora, Sintoli, Dhoga Bhool, Bhurumuni, Mostmanu, Sanghar, Jajroli, Godiya Gaon (01 each).

The density of Ageratina adenophora was also calculated in different ecosystems of the study area. As per our study, the maximum density of Ageratina adenophora in the fallow land was recorded in GodiyaGaon (248/m²), whereas, the minimum density was recorded in Bichcot village, which was 95.87/m². In case of invasion of agriculture land, the maximum density was recorded in Chera village (196.75/m²), whereas, the minimum was recorded from Jagtar village (70.5/m²). Chera village has a maximum invasion of Ageratina adenophora (200.7/m²) in terms of density in forest whereas; minimum (62.7/m²) was recorded in Bhurumuni village (Fig 3).

![Fig 2. Ageratina adenophora invasion in different villages of Gokerneshwer-gad watershed](image_url)
In terms of area, fallow lands had a maximum area of invasion followed by Agricultural land and grassland whereas, highest patch density was observed in most of the grasslands and agricultural lands of Gokerneshwer-gad watershed. The various ecological parameters which affected the distribution of *Ageratina adenophora* were as follows:

1. **Slope**: Slopes of landforms control the amount of rainwater accumulation. Within this region, the maximum presence of *Ageratina adenophora* was observed between 20° and 30° slope positions (Fig 4) as it requires moderate slope steepness for more stability. Slope (Titshall *et al.*, 2000) has also been reported to be one of the important parameters for invasive species distribution.

2. **Distance from road**: The results suggest that the distance from the road was inversely proportional to the growth of *Ageratina adenophora* invasion in the study area as the highest invasion (41.39%) was observed at roadsides (Fig 5). Similar patterns were also observed by various other workers in other ecosystems (Tyser and Worley, 1992; Parendes and Jones, 2000; Watkins *et al.*, 2003). Our results were also in line with (Kosaka, *et al.*, 2010) and (Bhattarai *et al.*, 2014), who reported that plant invasion in mountainous regions of India and Nepal was facilitated by road construction and the distribution varied with altitude.

3. **Land use cover type**: The maximum occurrence of *Ageratina adenophora* (Fig 6) was recorded in the fallow land (69.97%) followed by grassland (18.67%), agriculture (9.10%) and forest (2.26%). The success of invasive alien plants is due to their opportunistic exploitation of anthropogenic disturbances, the absence of natural enemies, and frequently, higher dispersal rate and competitive ability, (Kunwar, 2003; Simberloff *et al.*, 2005; Sharma *et al.*, 2005; Simberloff *et al.*, 2005).  

4. **Distance from water source**: Invasive plants have a major impact on catchment hydrology, (Geldenhuys, 1986) reported 30-70% lower water runoff from watershed areas with dense stands of alien species this was also supported by our results (Fig 7) as maximum presence of *Ageratina adenophora* (82%) was recorded near the water bodies (secondary and tertiary tributaries).

5. **Aspect**: A community strongly affected by aspect and this appears in the species distribution at special aspects. *Ageratina adenophora* was recorded highest at North (33.33%) followed by North-West (24.53%), South-West (11.57%), South (9.25%), West (8.79%), East (4.62%), North-East (4.16%) and lowest invasion was recorded in South-East (3.70%). Most of *Ageratina adenophora* was concentrated on the North and North-West direction, which gives the species more sheltered conditions (Fig 8).
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6. **Elevation:** A elevation determines the microclimate of an area; thus, it also determines the large-scale spatial distribution and patterns of vegetation (Busing *et al*., 1992). The relationship was further confirmed when the distribution and altitude maps were superimposed by GIS. It was observed that the highest *Ageratina adenophora* invasion (16.66%) was in between 1700 – 1800m elevation gradient and the lowest presence (3.70%) detected between 700 – 800m (Fig 9).
7. **Distance from the village:** During the study, it was noticed that the abundance and occurrence of *Ageratina adenophora* were inversely proportional to the distance from the village or disturbance site. As we moved away from the villages, less density and abundance of *Ageratina adenophora* was recorded (Fig. 10). Both natural and direct anthropogenic disturbances are known to promote invasion of exotic species (Hobbs and Huenneke, 1992) (Lozon and MacIsaac, 1997); (D'Antonio *et al*., 1999). Thus it could be concluded that the disturbance or anthropogenic activities are favourable for the distribution of *Ageratina adenophora*.

The number of clumps of *Ageratina adenophora* was found to be negatively correlated with the digital elevation (DEM) thus altitude plays an important role in distribution of this alien plant species and number of clumps was negatively correlated with mean number of plants per clump indicating that more the density of clumps lesser is the number of plants per clump in an area. Thus it may also be said that after acquiring an area, the species is competing to itself. A very interesting correlation was found between the environmental and ecological variables with the total clumps, total plants and mean number plants per clump of *Ageratina adenophora* in the study area (Table 1). The PCA shows a negative correlation between the clumps of *Ageratina adenophora* and altitude, indicating that the number of clumps of *Ageratina adenophora* decreases with increase in altitude whereas it also decreases with increase in distance from drainage and soil texture (Fig 11). A negative correlation of clumps to mean number of plants per clump was also found suggesting that as the number of clumps increase in an area, the mean number of plants per clump decreases which further indicates that after reaching a threshold level the alien plants start competing among themselves. Similarly, a positive correlation was found between total clumps and total *Ageratina adenophora* plants in the study area. On the other hand, a positive correlation was also found between the mean number of plants per clump and distance from road and village/settlements suggesting that this plant species prefer to remain in clumps as it moves away from the disturbance sites. The total number of clumps also increased with the decline in distance from the drainage suggesting that this species prefer habitats which are moist to dry habitats. Thus availability of water source is also one of the important factors in distribution of this alien plant species although it does not require more fertile land to grow as a negative correlation was found between total number of clumps of this plant species and soil texture.

![Fig 11. Factors responsible for distribution and invasion of *Ageratina adenophora*](image-url)

**Principal Component Analysis (PCA)**

| Variable                  | Loadings (F1) | Loadings (F2) |
|---------------------------|---------------|---------------|
| Distance from village     | -1            | -0.5          |
| Altitude                  | 0             | 0             |
| LULC                      | 0.5           | 1             |
| Clumps                    | 0             | 1             |
| Total Plants              | 0.5           | 1             |
| Mean No. of Plants/Clump | 0             | 1             |
| Distance from road        | -1            | -0.5          |
| Aspect                    | -0.5          | 0             |
| Slope                     | 0             | 1             |
| Soil texture              | 0             | 1             |
| Distance from drainage    | 0             | 1             |

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Table 1. Correlation between various factors and variables responsible for the distribution of *Ageratina adenophora*

|                     | slope | Altitude | Distance from village | Distance from road | Aspect | Distance from drainage | Soil texture | LULC | Clumps | Total Plants | Mean No. of Plants/Clump |
|---------------------|-------|----------|-----------------------|-------------------|--------|-----------------------|--------------|-------|--------|--------------|--------------------------|
| Slope               | 1     | -0.345   | 0.120                 | 0.238             | 0.176  | 0.074                 | 0.044        | -0.020| 0.081  | 0.061        | 0.041                    |
| Altitude            | -0.345| 1        | 0.343                 | -0.674            | -0.178 | -0.187                | 0.152        | 0.102 | -0.165 | -0.133       | -0.107                   |
| Distance from village| 0.120 | 0.343    | 1                     | -0.080            | 0.003  | -0.112                | -0.209       | 0.294 | 0.011  | 0.001        | -0.005                   |
| Distance from road  | 0.238 | -0.674   | -0.080                | 1                 | 0.121  | 0.495                 | 0.094        | -0.250| 0.004  | 0.146        | 0.208                    |
| Aspect              | 0.176 | -0.178   | 0.003                 | 0.121             | 1      | -0.057                | -0.047       | 0.134 | 0.058  | 0.010        | -0.035                   |
| Distance from Drainage| 0.074 | -0.187   | -0.112                | 0.495             | -0.057 | 1                     | 0.097        | -0.157| -0.156 | -0.098       | 0.035                    |
| Soil texture        | 0.044 | 0.152    | -0.209                | 0.094             | -0.047 | 0.097                 | 1            | -0.262| -0.140 | 0.009        | 0.036                    |
| LULC                | -0.020| 0.102    | 0.294                 | -0.250            | 0.134  | -0.157                | -0.262       | 1     | -0.028 | 0.012        | -0.012                   |
| Clumps              | 0.081 | -0.165   | 0.011                 | 0.004             | 0.058  | -0.156                | -0.140       | -0.028| 1      | 0.320        | -0.237                   |
| Total Plants        | 0.061 | -0.133   | 0.001                 | 0.146             | 0.010  | -0.098                | 0.009        | 0.012 | 0.320  | 1            | 0.779                    |
| Mean No. of Plants/Clump | 0.041 | -0.107   | -0.005                | 0.208             | -0.035 | 0.035                 | 0.036        | -0.012| -0.237 | 0.779        | 1                        |

*In bold, significant values (except diagonal) at the level of significance alpha=0.050 (two-tailed test)*
Conclusion
Plant invasions in the new areas cause huge economic and ecological imbalance by altering native community composition, depletion of species diversity thus affecting the ecosystem process. The increased incidence of invasion in high altitudinal ecosystems possesses a major threat to the indigenous biological diversity of the region. The results indicate that four environmental variables viz. altitude; soil texture, distance from disturbance site such as road and village/settlement as well as a water source as the distance from nearest drainage, play a major role in the distribution and invasion of *Ageratina adenophora*. This species prefers and occupies such habitats which are degraded, disturbed and the habitats where the anthropogenic pressure is much higher than other habitat types in any ecosystem and does not require much fertile land to invade. Some serious mitigation techniques and measures are required to check the further distribution of this alien species in the western Himalayan region as this species was recorded up to an elevation of about 2100 masl. The further distribution of this alien species in the Himalayan region may cause a serious threat to the local biodiversity and a change in ecosystem process of the area causing loss of vital ecosystem services.

Acknowledgements
The authors are thankful to ICIMOD, Nepal and Ministry of Environment and Forestry for funding and facilitating the study under various grants. The authors are also thankful to Director, Dean and other staff members of Wildlife Institute of India for their continuous help and support throughout the study period.

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