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Roadside Distribution Patterns of Invasive Alien Plants Along an Altitudinal Gradient in Arunachal Himalaya, India

Yasuyuki Kosaka[1]*, Bhaskar Saikia[2], Tasong Mingki[2], Hui Tag[2], Tomo Riba[3], and Kazuo Ando[4]

** Corresponding author: kosaka@chikyu.ac.jp*
[1] Research Institute for Humanity and Nature; 457-4 Motoyama Kamigamo, Kita-ku, 603-8047, Kyoto, Japan
[2] Department of Botany, Faculty of Life Sciences, Rajiv Gandhi University, Rono Hills, Itanagar, 791112, Arunachal Pradesh, India
[3] Department of Geography, Faculty of Environmental Sciences, Rajiv Gandhi University, Rono Hills, Itanagar, 791112, Arunachal Pradesh, India
[4] Center for Southeast Asian Studies, Kyoto University, 46 Yoshidashimoadachi-cho, Sakyo-ku, 606-8501, Kyoto, Japan

Invasive plants have spread all over the world, including the Himalayan region. In 2009, the distribution pattern of invasive alien plants was studied on 38 plots, from 100 to 4200 m, in Arunachal Pradesh and Assam, India. Eighteen invasive alien plants (frequency >5%) from 7 families were recorded, of which 15 species (83.3%) were from North and South America. The most common plants by both frequency and coverage (>50%) were Ageratum conyzoides*,* Chromolaena odorata*, and* Mikania micrantha*. Species composition changed with altitude. Thirteen species grew in the tropical zone, 10 in the subtropical, 6 in the temperate. and 1,* Taraxacum officinale*, in the subalpine zone. We suggest that low temperature and snowfall in the highlands may filter nonadapted species from tropical regions and that recent construction and use of roads facilitate the establishment of invasive alien plants. Although several invasive alien plants were regarded as noxious weeds, local residents in the study area mentioned their beneficial uses:* A. conyzoides *and* Solanum carolinense *are used as medicine,* Galinsoga quadriradiata *is used as a vegetable, and* Eichhornia crassipes *is used to improve fish growth in aquaculture. Information from scientific assessment and local perception of invasive alien plants will assist in the development of appropriate plant resource management plans in Arunachal Himalaya.*

Keywords: *Altitudinal gradient; plant invasion; perception of local residents; plant resource management; road construction; Arunachal Pradesh; Assam; India.*

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Introduction

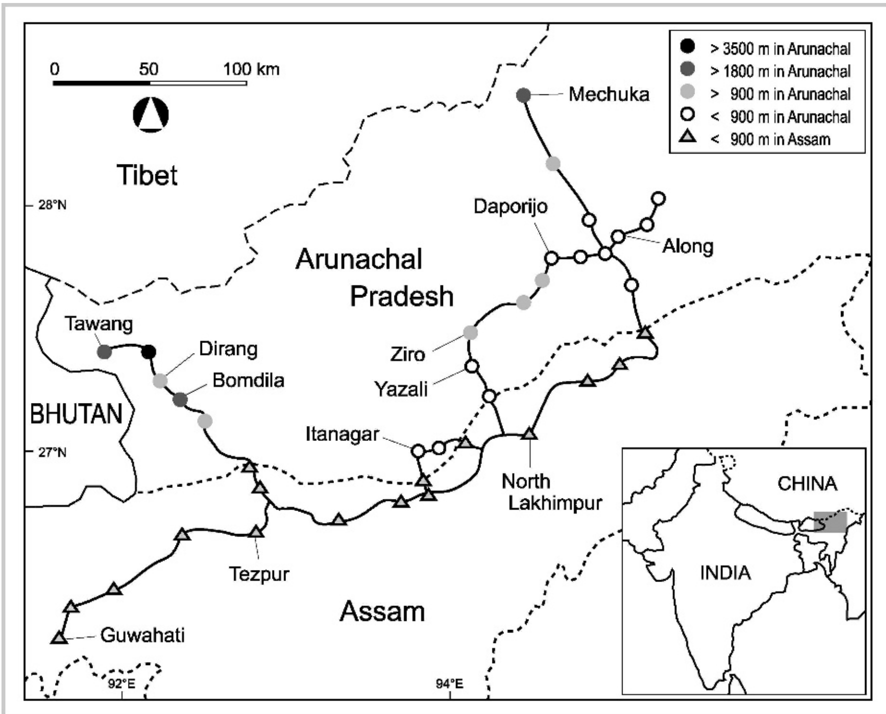
Many plant species have been either accidentally or deliberately translocated far from their native areas (Khuroo et al 2007). Newly introduced plants, called alien plants (Pysek et al 2004), have various effects on the environment and economy of non-native areas. Some alien species, often cultivated, may provide food, medicine, fuel, or fodder to local communities (Kull et al 2007; Roder et al 2007). Other alien species have negative impacts on agricultural production, forest regeneration, livestock grazing, native vegetation, and ecosystems or human health (Pimentel et al 2000; Sharma et al 2005; Kohli et al 2006). Introduced species with high reproductive rates and the potential to spread rapidly over large areas are regarded as invasive alien plants (Pysek et al 2004).

The Himalayan region has also been invaded by alien plants (Khuroo et al 2007). The vegetation of Arunachal Himalaya is known for its great diversity and endemism (Behera et al 2002; Hegde 2003; Bhagabati et al 2006), and many plants are used for food, medicine, resin, fiber, handicrafts, or cultural rituals (Tag and Das 2004; Tag et al 2008). There have been few studies of invasive alien plants in this region, and information is required for management planning.

Arevalo et al (2005) and Pickering and Hill (2007) report that road construction facilitated plant invasion in mountainous regions and that the distribution pattern of invasive plants along roadsides varied with altitude. Arevalo et al (2005) found the highest number of alien plants at intermediate altitudes between 0 and 2000 m. Pauchard and Alaback (2004) showed that alien species richness was negatively correlated with elevation along roadsides between 280 and 1290 m. Similar patterns of invasion after road construction and distribution with altitude may also apply to the Arunachal Himalaya region.

The present study compiled information on the distribution patterns of some invasive alien plants alongside roads in Arunachal Himalaya and gathered information on cultural perceptions of invasive plants for development of plant resource management.

FIGURE 1 Map of 38 roadside plots in Arunachal Himalaya. (Map by Y. Kosaka)



Material and methods

Study area

Arunachal Pradesh (26°28′–29°31′N; 91°30′–97°30′E) and Assam (24°09′–27°58′N; 89°42′–96°01′E) are located at the eastern end of the Himalayan region at altitudes between 100 and 7000 m. There are 3 seasons per year: a warm and dry summer (March–May), monsoon (June–September), and a cool and dry winter (October–February). About 85% of annual rainfall (3000 mm) occurs during the monsoon season. Mean annual maximum and minimum temperatures are 29.3°C and 19.2°C in Itanagar (200 m), 27°C and 16°C in Along (300 m), 22°C and 12°C in Ziro (1600 m), and 19°C and 5°C in Tawang (3000 m), respectively (Purkayastha 2008).

Vegetation types vary with altitude and climatic conditions, from tropical (below 900 m), subtropical (900–1800 m), temperate (1800–3500 m) to subalpine and alpine (above 3500 m). Rice is cultivated below 2000 m on the plain and valley floor, whereas shifting cultivation is conducted on hillsides up to 2500 m. Livestock, such as yak, yak-cattle hybrids, and sheep, are bred by highlanders and pastured above 3000 m.

There has been regional trade between Tibet and Arunachal Himalaya for centuries (Choudhury 1981; Choudhury 1996). However, Arunachal Himalaya was called the "hidden land," because access for outside visitors was difficult (Blackburn 2003). After independence in 1947, the Indian government began a development program to construct roads, increase agricultural production, and improve public health (Elwin 1959). Nowadays, tourism is a significant economic activity, and many domestic and foreign tourists visit the region.

Material and methods

A total of 38 roadside plots at 5–30 km intervals were selected (Figure 1) along the Assam national highway (75–250 m) and a state major road in Arunachal Pradesh (200–4200 m). Twenty-eight plots were in the tropical zone, 6 in subtropical, 3 in temperate, and 1 in subalpine and alpine zones. Strip-shaped plots alongside and parallel to the roads were sampled. Plot sizes varied from 50 m × 5 m to 200 m × 10 m because of variable land use, topography, and roadside vegetation. Between 2 and 5 replicates of a 50-m transect were sampled on each plot.

The abundance of alien species was recorded on a qualitative scale (Pauchard and Alaback 2004): A, abundant (present in >25% of the transect length); C, common (10–25%); I, intermittent (< 10%); and R, rare when only 1 group of individuals was present. Species abundance was determined by the maximum value recorded along the transects within the plot. A subjective percentage cover value was assigned to each of the qualitative abundance classes (Pauchard and Alaback 2004): A = 50, C = 25, I = 10 and R = 1. The location and altitude of the plots were recorded by global positioning system (GPS; Garmin GPSmap 60Cx).

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TABLE 1 Summary of the invasive alien plants in Arunachal Himalaya. (Table extended on next page.)

Scientific name	Family	Origin[a)]	Frequency (%)	Growth form[b)]
Ageratum conyzoides L.	Asteraceae	AMS	58.0	Ah
Ambrosia artemisiifolia L.	Asteraceae	AMN	7.9	Ah
Bidens pilosa L.	Asteraceae	AMS	37.0	Ah
Ageratina adenophora (Spreng.) King & H. E. Robins	Asteraceae	AMS	5.3	P/S
Chromolaena odorata (L.) King & H. E. Robins	Asteraceae	AMS	68.4	P/S
Galinsoga quadriradiata Ruiz & Pav.	Asteraceae	AMS	10.5	Ah
Mikania micrantha Kunth	Asteraceae	AMS	55.3	C
Parthenium hysterophorus L.	Asteraceae	AMS	7.9	Ah
Taraxacum officinale (L.) Weber ex F. H. Wigg	Asteraceae	EU	10.5	P
Ipomoea carnea Jacq.	Convolvulaceae	AMS	7.9	S
Crotalaria pallida Aiton	Fabaceae	AF	13.1	Ah/P
Mimosa pudica L.	Fabaceae	AMS	7.9	Ah/P
Trifolium repens L.	Fabaceae	EU	5.3	P
Cuphea carthagenensis (Jacq.) Macbr.	Lythraceae	AMS	15.8	Ah/P
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	AMS	18.4	Aq
Solanum carolinense L.	Solanaceae	AMN	63.1	P
Lantana camara L.	Verbenaceae	AMS	18.4	S
Stachytarpheta dichotoma Vahl.	Verbenaceae	AMS	28.9	P

[a)] Origin of alien species: AF, Africa; AMN, North America; AMS, South America; EU, Europe.
[b)] Growth form: Ah, annual herb; Aq, aquatic; C, climber; P, perennial herb; S, shrub.

Additional habitats of invasive alien plants were recorded (arable field, grassland, settlement area, water body) through direct observation and field interviews. In North Lakhimpur, Along, and Ziro, 3–5 knowledgeable local residents were asked when they first detected invasive alien plants, the habitat in which they were detected, the mode of introduction, harmful effects, and beneficial uses. A literature survey of known harmful effects or beneficial uses was completed for each plant identified. Data on species of Cyperaceae and Poaceae were not collected, because many individuals of these species were not in flower during the survey period, and accurate identification requires inflorescence.

Relative abundance and frequency were calculated for recorded species, and data were analyzed by detrended correspondence analysis (DCA) (Hill and Gauch 1980). Species compositional gradients among the plots were detected by PC-ORD version 5. The ordination matrix contained 37 plots (1 plot lacked alien species) and 18 species. Species with frequencies of $\leq 5\%$ were excluded from analysis because minor species may cause unnecessary noise. The correlation between plot score in DCA axis 1 and elevation was tested by linear regression.

Alien plant species were determined as those not native to the eastern Himalayan region. The nomenclature, origin, growth form (Khuroo et al 2007), mode of reproduction, and mode of dispersal were recorded by following Harada et al (1993), Takematsu and Ichizen (1987, 1993, 1997), and Weber (2003).

Results

Characteristics of invasive alien plants in Arunachal Himalaya

A total of 18 invasive alien plants (frequency $>5\%$) were recorded on 38 plots (Table 1). The dominant family was Asteraceae (9 species) followed by Fabaceae (3) and Verbenaceae (2). Most species originated in South America (13); others originated in North America (2), Europe (2), and Africa (1). Nine species also grew in arable fields, 3 in grassland, 3 in settlement areas, and 2 in water bodies. Ten species only reproduced by seed, 1 species by vegetative reproduction, and 7 species by both seed and vegetative

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TABLE 1 Extended. (First part of Table 1 on previous page.)

Scientific name	Habitat[c)]	Reproduction[d)]	Dispersal[e)]	Introduction[f)]
Ageratum conyzoides L.	A, G, R, S	S	A, OH	U
Ambrosia artemisiifolia L.	R	S	En, OH	U
Bidens pilosa L.	A, R	S	Ep, OH	U
Ageratina adenophora (Spreng.) King & H. E. Robins	A, R	S	A	U
Chromolaena odorata (L.) King & H. E. Robins	A, R	S	A	U
Galinsoga quadriradiata Ruiz & Pav.	A, G, R, S	S	A	U
Mikania micrantha Kunth	A, R	S, V	A, En, OH	U
Parthenium hysterophorus L.	R	S	A, OH	U
Taraxacum officinale (L.) Weber ex F. H. Wigg	R	S, V	A	U
Ipomoea carnea Jacq.	R, W	S, V	H	I
Crotalaria pallida Aiton	R	S	A, En, OH	U
Mimosa pudica L.	R	S	A, En, OH	U
Trifolium repens L.	R	S, V	A, En, OH	I
Cuphea carthagenensis (Jacq.) Macbr.	R	S	A, En, OH	U
Eichhornia crassipes (Mart.) Solms	A, R, W	V	H	I
Solanum carolinense L.	A, G, R	S, V	A, En, OH	U
Lantana camara L.	R	S, V	A, En, OH	I
Stachytarpheta dichotoma Vahl.	A, R, S	S, V	A, En, OH	U

[c)] Habitat: A, arable field; G, grassland; R, roadside; S, settlement area; W, water body.
[d)] Mode of reproduction: S, reproduction with seed; V, vegetative reproduction.
[e)] Mode of dispersal: A, anemochory; En, endozoochory; Ep, epizoochory; H, hydrochory; OH, ombrohydrochory.
[f)] Mode of introduction: I, intentionally introduced; U, unintentionally introduced.

reproduction. Aside from direct or indirect anthropogenic intervention, common dispersal modes included anemochory, endozoochory, and ombrohydrochory. *Bidens pilosa* also depends on epizoochory and *Ipomoea carnea* and *Eichhornia crassipes* are dispersed by hydrochory. Although most species were unintentionally introduced into this region, 4 species were intentionally introduced for beneficial uses (Table 2).

Species composition by altitude

The 37 plots were arranged along DCA axis 1 (eigen value [EIG] = 0.85) in order of altitude ($R = 0.92$, $P < .001$), whereas DCA axis 2 (EIG = 0.36) was slightly related to record location, Arunachal or Assam (Figure 2).

The number of species per plot varied from 2 to 8 in the tropical zone, from 3 to 8 in the subtropical zone, from 3 to 6 in the temperate zone, and only 1 species in the subalpine zone (Figure 3). The number of species per plot had no significant correlation with altitude ($R = 0.36$) (Figure 3).

The highest number of species (13) grew in the tropical zone, followed by the subtropical (10), temperate (6), and subalpine zones (1) (Figure 4). *Parthenium hysterophorus*, *Ipomoea carnea*, *Crotalaria pallida*, *Mimosa pudica*, *Cuphea carthagenensis*, and *Stachytarpheta dichotoma* grew only in the tropical zone. *Ageratum conyzoides*, *Ambrosia artemisiifolia*, *Bidens pilosa*, and *Solanum carolinense* grew in the widest range of habitats, from tropical to temperate zones. Except for these 4, species growing in the subtropical zone were recorded up to 1600 m, whereas species found in the temperate zone occurred above 1600 m. Few temperate zone species grew above 3000 m. Only 1 species, *Taraxacum officinale*, was recorded on the mountain pass at 4200 m, the highest plot in the present study (Figure 4).

Harmful effects and beneficial uses of invasive alien plants

Among 18 alien plants recorded, harmful effects were identified on crop production (14 species), livestock grazing (7), human health (4), water drainage (2), forest regeneration (1), and native vegetation (1), whereas beneficial uses were recorded as medicine (12), vegetable (4), fodder (2), hedge plant (2), fish growth (1), fallow plant (1), fish poison (1), manure (1), soil protection from erosion (1), and ornament (1).

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TABLE 2 Harmful effects and beneficial uses of invasive alien plants recorded in Arunachal Himalaya and other regions.[a]

Scientific name	Harmful effect[b]	Use[c]
Ageratum conyzoides	CP[1,3]	Md[1,5,10,12]
Ambrosia artemisiifolia	CP[13], HH[13]	–
Bidens pilosa	CP[2, 13]	Md[5], V[11]
Ageratina adenophora	CP[7], HH[1], LG[13]	Md[5]
Chromolaena odorata	CP[13], HH[1], LG[13]	FL[8], FP[13], Md[5,12], Mn[13]
Galinsoga quadriradiata	CP[2,13], LG[5]	Fd[14], Md[5], V[1]
Mikania micrantha	CP[1,3,13]	Md[12,13]
Parthenium hysterophorus	CP[13], HH[3]	Md[13]
Taraxacum officinale	CP[13], NV[6]	Md[10,13], V[5,13]
Ipomoea carnea	WD[1]	H[5], Md[5], SP[1,13]
Crotalaria pallida	LG[13]	–
Mimosa pudica	CP[13], LG[13]	Md[5]
Trifolium repens	–	Fd[5,9]
Cuphea carthagenensis	–	–
Eichhornia crassipes	CP[1,2,13], WD[13]	FG[1], O[13], V[5]
Solanum carolinense	CP[2,13], LG[13]	Md[1]
Lantana camara	CP[3,4,13], FR[3,4,13],LG[5]	H[5], Md[10]
Stachytarpheta dichotoma	CP[1,13]	–

[a] Sources: 1) Personal observation, 2) Harada et al (1993), 3) Kohli et al (2006), 4) Love et al (2009), 5) Manandhar (2002), 6) Pickering and Hill (2007), 7) Ramakrishnan and Mishra (1981), 8) Roder et al (1995), 9) Roder et al (2007), 10) Sharma (2001), 11) Tag and Das (2004), 12) Tag et al (2008), 13) Takematsu and Ichizen (1987, 1993, 1997), 14) Toukura et al (2008).

[b] Harmful effects on: CP, crop production; FR, forest regeneration; HH, human health; LG, livestock grazing; NV, native vegetation; WD, drainage.

[c] Beneficial uses: Fd, fodder; FG, improving fish growth; FL, fallow plant; FP, fish poison; H, hedge; Md, medicine; Mn, manure; O, ornamental; SP, soil protection from erosion; V, vegetable.

FIGURE 2 DCA diagram of plots classified by altitude and location in Arunachal Himalaya. Five areas in 4 altitude zones correspond with vegetation zones.

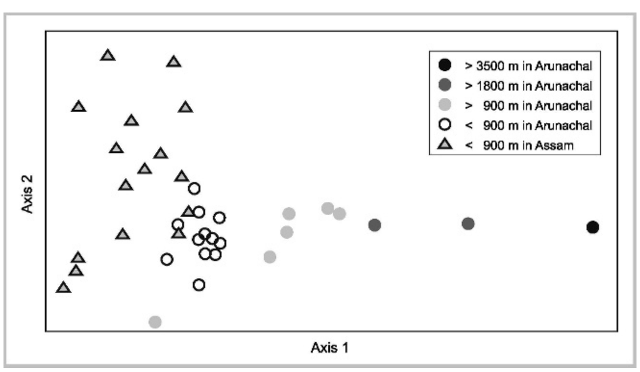

FIGURE 3 Number of species per plot at different altitudes in Arunachal Himalaya.

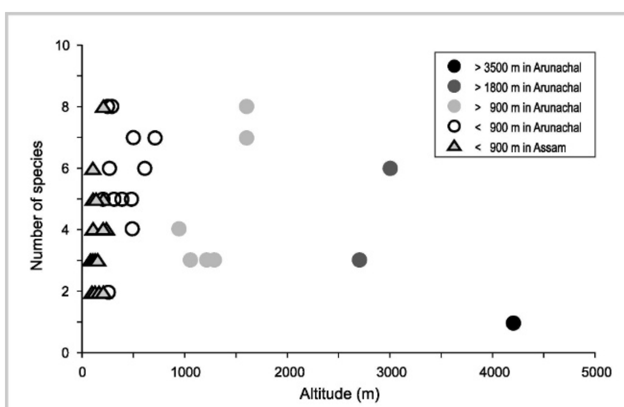

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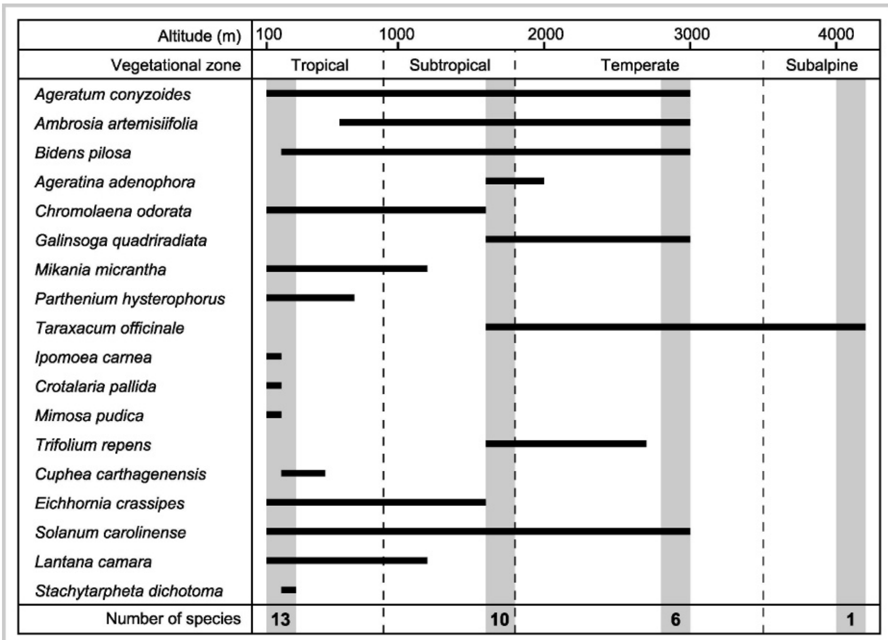
FIGURE 4 Altitudinal range of invasive alien plants found in Arunachal Himalaya.



Discussion

Distribution patterns of invasive alien plants

Most (83.3%) of the invasive alien plants in the Arunachal Himalaya region originated in North and South America (Table 1). *A. conyzoides*, *B. pilosa*, *Galinsoga quadriradiata*, and *P. hysterophorus* have been reported from Nepal (Manandhar 2002) and Kashmir Himalaya (Khuroo et al 2007), and these species may be spreading in the Himalayan region.

Although species composition changed with the altitudinal gradient (Figure 2), the number of species per plot was not related to altitude (Figure 3). The altitudinal range of species (Figure 4) corresponded with known biogeographical affinities and environmental tolerances. Temperate species were limited to highlands (above 1600 m), whereas 10 species of tropical origin (62.5%) were limited to lowlands (below 1600 m). Apart from *T. officinale*, alien species were not recorded above 3000 m where the temperature dropped to below the freezing point in the winter (Figure 4). Low temperature and snowfall in the highlands may filter nonadapted species from tropical regions (Pauchard and Alaback 2004; Arevalo et al 2005).

Plant invasions are influenced by climate; *Ageratina adenophora*, *Chromolaena odorata*, *Mikania micrantha*, *E. crassipes*, and *Lantana camara* were regarded as invasive in tropical Asia but not in temperate Asia (Weber 2003).

Plant invasion through recent road construction

Some alien plants were introduced into Himalayan regions by historical trading (Khuroo et al 2007), but Pickering and Hill (2007) suggest that recent road construction and road use facilitate the establishment of invasive alien plants in mountain regions. This view was supported by the recollections of elderly residents at the study sites. In Along (270 m), residents reported that *S. carolinense* was found after a road was built to Assam before 1990. *M. micrantha* and *S. dichotoma* have expanded their range since 2000. In Ziro (1600 m), *A. artemisiifolia* and *S. carolinense* spread after the road was connected from Assam in the 1950s. The spread of *S. carolinense* was related to the introduction of cattle from Assam that disseminated its seed. *E. crassipes* was introduced in 1970s, followed by *G. quadriradiata* after 2000.

Unintentionally introduced alien plants may subsequently disseminate seed or vegetative propagates by wind, water, or animals (Table 1). Burning in shifting cultivation also promotes the establishment of *A. adenophora* and *C. odorata* (Tripathi and Yadav 1987), as well as *M. micrantha* (Swamy and Ramakrishnan 1987).

Perception of local residents

Local informants reported harmful effects of invasive alien plants (Table 2). *I. carnea* impedes drainage and *E. crassipes* prostrates rice plants when plants drift onto wet fields during seasonal floods in North Lakhimpur. *M. micrantha* and *S. dichotoma* were reported to damage agricultural production by overhanging crops in Along. The spines on *S. carolinense* disturbed agriculture in Yazali. *A. conyzoides* and *G. quadriradiata* were regarded as major weeds, and downy fruits of *A. adenophora* and *C. odorata* were reported to cause breathing problems in Dirang.

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Beneficial uses of invasive alien plants were also reported (Table 2). The leaf of *A. conyzoides* was squeezed and applied to wounds as styptic. *E. crassipes* was introduced to improve fish growth in aquaculture in Ziro. The young leaf of *G. quadriradiata* was eaten as a vegetable, and the fruit of *S. carolinense* was used as medicine against toothache in Dirang.

Conclusion

A total of 18 invasive alien plants, mostly from North and South America, were recorded from the Arunachal Himalaya area. Most species grew in the tropical zone, followed by the subtropical, temperate, and subalpine zones. Low temperature and snowfall in the highlands may filter nonadapted species from tropical regions. Data from a survey of residents and prior studies suggest that recent construction and use of roads facilitate the establishment of invasive alien plants. Although residents identified harmful effects of some alien plants, other plants were used as beneficial resources. The views of local residents and the benefits to subsistence livelihoods should be incorporated into ecosystem management planning.

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