State-level inventory of invasive alien plants, their source regions and use potential

K. P. Singh[1], Achuta Nand Shukla[1] and J. S. Singh[2,*]

[1]Botanical Survey of India, Central Circle, Allahabad 211 002, India
[2]Department of Botany, Banaras Hindu University, Varanasi 221 005, India

A comprehensive inventory of the invasive alien flora of India's fifth largest and most populous state, Uttar Pradesh, revealed 152 species from 109 genera and 44 families. Dicots represented 137 species and monocots 15 species. About 73% of these alien species were introduced from tropical America including South America, followed by tropical Africa (10.5%). Maximum number of species (30) were from the family Asteraceae, followed by Fabaceae (12 species), and then Amaranthaceae, Solanaceae and Convolvulaceae with eight species each. Herbs accounted for 128 species, shrubs 12 species, climbers 8 species, whereas trees and lianas 3 and 1 species respectively. People have found a large number of these alien species useful.

Keywords: Invasive alien species, India, Uttar Pradesh.

INVASIVE alien species are species whose introduction or spread threatens the environment, the economy or society, including human health (http://www.cbin.ec.gc.ca/ssues/ias). Biological invasions by alien species are widely recognized as a significant component of human-caused global environmental change, often resulting in a significant loss in the economic value, biological diversity and change in aspects of functioning of invaded ecosystems[1]. From an ecological perspective, any species introduced to an ecosystem beyond its home range that establishes, naturalizes and spreads is said to be invasive[2]. Introduction of these species may occur accidentally or through their being imported for a limited purpose and subsequently escaping, or deliberately on a large scale[3]. Many people introduce non-native species into new habitats for economic reasons[4], and most cases of invasiveness can be linked to the intended or unintended consequences of economic activities[5]. Globalization and rapid modification of natural habitats have particularly accelerated the pace of invasion during the past century[6]. At the continental and global scale, species invasions have diminished the regional distinctiveness of flora and fauna[7]. In many continental areas 20% or more of the plant species are now non-indigenous. On many islands the proportion of non-indigenous plant species is 50% or more[8].

*For correspondence. (e-mail: singh.js1@gmail.com)

Invasive weeds have faster rates of growth and biomass production compared to native species, high competitive ability, high reproductive efficiency including production of a large number of seeds, efficient dispersal, vegetative reproduction, rapid establishment and other traits that help them adapt to new habitats[9,10]. Many of these species have allelopathic potential and possess high tolerance to different abiotic conditions[10,11]. Nevertheless, both the biotic and abiotic properties of the target habitat are likely to be as important as the autecological attributes of the invading species in influencing invasive success[12].

At least 10% of the world's vascular plants (300,000) have the potential to invade other ecosystems and affect native biota in direct or indirect ways[13]. About 18% of the Indian flora constitutes aliens, of which 55% are American, 30% Asian and Malaysian and 15% European and Central Asian species[14].

There is an apparent need for a regional and national authentic database on invasive aliens for monitoring the spread and impact in various regions and for devising appropriate management strategies. The present study reports the invasive alien plant species in the flora of Uttar Pradesh (UP), which is India's fifth largest and most populous state.

UP is located between 23°52′N–31°28′N lat. and 77°3′E–84°39′E long. The altitude varies between 50 and 500 m above mean sea level. The climate of the state is tropical monsoonal with annual rainfall varying between 600 and 2000 mm. The average maximum and minimum temperatures are 48°C and 2°C respectively. There are three distinct seasons: winter from October to February, summer from March to mid-June, and rainy from June to September.

Intensive field studies were conducted in a planned manner repeatedly in different seasons from 2002 to 2008 in order to get maximum representation of invasive alien species. Almost the entire geographical area (ca. 80%, all the 71 districts) was surveyed. Plant samples were collected from natural habitats, agricultural lands, wastelands including usar (saline–alkaline) lands, village ponds, wet lands, marshy lands, ravines of Chambal area, along the railway tracks, protected areas, river banks, reserve forests, etc. to document almost all the floristic components including invasive alien species of UP. Specimens collected were deposited in the Botanical Survey of India (BSI) herbarium at Central Circle, Allahabad. During repeated field visits, qualitative observations on spread and important species traits associated with invasiveness[10] were made. The information available in the literature[15–33] and in different herbaria like National Botanical Research Institute, Lucknow, BSI at Allahabad and Dehradun, Central National Herbarium, Kolkata, Forest Research Institute, Dehradun, universities of Allahabad and Gorakhpur, etc. has also been incorporated while documenting the invasive alien species.

Table 1. Invasive alien plant species of Uttar Pradesh, their source region and use potential

Species	Family	OR	LF	HA	U	HT	MI
Acacia farnesiana (L.) Willd.	Mimosaceae	SAM	T	P	M	AR	Ui
Acanthospermum hispidum DC.	Asteraceae	BR	H	A	M	W	Ui
Aerva javanica (Burm.f.) Juss. ex Schult.	Amaranthaceae	TAM	H	A	M	CF	Ui
Aeschynomene americana L.	Fabaceae	TAM	H	A	Co	CF	Ui
Ageratum conyzoides L.	Asteraceae	TAM	H	A	M	W	O
Ageratum houstonianum Mill.	Asteraceae	TAM	H	A	Ch	W	Ui
Alternanthera paronychioides St. Hill.	Amaranthaceae	TAM	H	P	M	RB	Ui
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	TAM	H	P	Nk	RB	Ui
Alternanthera pungens Kunth	Amaranthaceae	TAM	H	P	Ch, M	W	Ui
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	TAM	H	P	Ch, M	RB	Ui
Amaranthus spinosus L.	Amaranthaceae	TAM	H	A	M	CF	Ui
Anagallis arvensis L.	Primulaceae	EU	H	A	M	CF	Ui
Antigonon leptopus Hook. & Arn.	Polygonaceae	TAM	C	P	M	AR	Ui
Argemone mexicana L.	Papaveraceae	SAM	H	A	Ad, M	W	Ui
Asclepias curassavica L.	Asclepiadaceae	TAM	H	P	Ch	AR	Ui
Bidens pilosa L.	Asteraceae	TAM	H	A	M	CF	Ui
Blainvillea acmella (L.) Philipson	Asteraceae	TAM	H	A	Ch	W	Ui
Blumea eriantha DC.	Asteraceae	TAM	H	P	Ch	W	Ui
Blumea lacera (Burm.f.) DC.	Asteraceae	TAM	H	A	M	W	Ui
Blumea obliqua (L.) Druce	Asteraceae	TAM	H	A	Ch	W	Ui
Borassus flabellifer L.*	Arecaceae	TAF	T	P	Hf	W	Ui
Caldesia oligococca (F.v. Muell.) Buchenau*	Alismataceae	AS	H	P	Nk	RB	Ui
Calotropis gigantea (L.) R.Br.	Asclepiadaceae	TAF	S	P	M	W	Ui
Calotropis procera (Ait.) R.Br.	Asclepiadaceae	TAF	S	P	M	W	Ui
Cardamine hirsuta L.	Brassicaceae	TAM	H	P	Nk	RB	Ui
Cassia absus L.	Caesalpiniaceae	TAM	H	A	M	W	Ui
Cassia alata L.	Caesalpiniaceae	WI	S	P	M	W	Ui
Cassia obtusifolia L.	Caesalpiniaceae	TAM	H	P	M	W	Ui
Cassia occidentalis L.	Caesalpiniaceae	SAM	H	P	M	W	Ui
Cassia pumila Lam.*	Caesalpiniaceae	TAM	H	A	Ch	W	Ui
Cassia tora L.	Caesalpiniaceae	SAM	H	A	M, Bf	W	Ui
Catharanthus pusillus G. Don	Apocynaceae	TAM	H	A	Ch	CF	O
Celosia argentea L.	Amaranthaceae	TAM	H	A	Ch, M	CF	Fd
Ceratophyllum demersum L.	Ceratophyllaceae	TAM	H	A	M	A	Ui
Chenopodium album L.	Chenopodiaceae	EU	H	A	V	CF	Fd
Chloris barbata Sw.	Poaceae	TAM	H	P	Fo	W	Ui
Chrozophora rottleri (Geis.) Spreng.	Euphorbiaceae	TAF	H	A/P	Ch	W	Ui
Cleome gynandra L.	Capparaceae	TAM	H	A	M	W	Ui
Cleome monophylla L.	Capparaceae	TAF	H	A	M	AR	Ui
Cleome rutidosperma DC.	Capparaceae	TAM	H	A	M	W	Ui
Cleome viscosa L.	Capparaceae	TAM	H	A	M	W	Ui
Conyza canadensis (L.) Cronquist	Asteraceae	SAM	H	A	Ch	F	Ui
Corchorus aestuans L.	Tiliaceae	TAM	H	A	M	W	Ui
Corchorus fascicularis Lam.	Tiliaceae	TAM	H	A	Ch	W	Ui
Corchorus olitorius L.	Tiliaceae	TAF	H	A	Ch	CF	Ui
Corchorus tridens L.	Tiliaceae	TAF	H	A	V	W	Ui
Corchorus trilocularis L.*	Tiliaceae	TAF	H	A	Ch	W	Ui
Crassocephalum crepidioides (Benth.) S. Moore	Asteraceae	TAM	H	A	Ch	F	Ui
Crotalaria pallida Dryand	Fabaceae	TAM	H	A	Ch	CF	Ui
Crotalaria retusa L.*	Fabaceae	TAM	H	A	Ch	CF	Ui
Croton bonplandianum Boil.	Euphorbiaceae	SAM	H	P	Ch	W	Ui
Cryptostegia grandiflora R.Br.*	Asclepiadaceae	MG	L	P	M	F	Ui
Cuscuta chinensis Lam.	Cuscutaceae	MR	C	P	M	P	Ui
Cuscuta reflexa Roxb.	Cuscutaceae	MR	C	A	M	P	Ui
Cyperus difformis L.	Cyperaceae	TAM	H	A	Ch	CF	Ui
Cyperus iria L.	Cyperaceae	TAM	H	A	Ch	CF	Ui
Cytisus scoparius (L.) Link*	Fabaceae	EU	H	A	M	CF	Ui
Datura innoxia Mill.	Solanaceae	TAM	S	P	M	W	Ui
Datura metel L.	Solanaceae	TAM	S	P	M	W	Ui
Dicoma tomentosa Cass.	Asteraceae	TAM	H	A	M	W	Ui
Digera muricata (L.) Mart.	Amaranthaceae	NAM	H	A	V	CF	Ui

(*Contd*)

Table 1. (*Contd*)

Species	Family	OR	LF	HA	U	HT	MI
Dinebra retroflexa (Vahl) Panz.*	Poaceae	TAM	H	P	Nk	CF	Ui
Echinochloa colona (L.) Link*	Poaceae	SAM	H	A	M	RB	Ui
Echinochloa crusgalli (L.) P.Beauv.[#,]*	Poaceae	SAM	H	A	Ad	RB	Ui
Echinops echinatus Roxb.	Asteraceae	AF	H	A	M	W	Ui
Eclipta prostrata (L.) L.*	Asteraceae	TAM	H	A	M	CF	Ui
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	TAM	H	P	Co, St	A	O
Emilia sonchifolia (L.) DC.	Asteraceae	TAM	H	A	Ch	RB	Ui
Euphorbia heterophylla L.	Euphorbiaceae	TAM	H	A	O	CF	Ui
Euphorbia hirta L.	Euphorbiaceae	TAM	H	A	M	CF	Ui
Evolvulus nummularius (L.) L.	Convolvulaceae	TAM	H	P	Ch	W	Ui
Flaveria trinervia (Spreng.) C.Mohr.	Asteraceae	CAM	H	A	M	W	Ui
Galinsoga parviflora Cav.	Asteraceae	TAM	H	A	M	RB	Ui
Glossocardia bosvallea (L.f.) DC.*	Asteraceae	WI	H	A	M	F	Ui
Gnaphalium pensylvanicum Willd.	Asteraceae	TAM	H	A	Nk	RB	Ui
Gnaphalium polycaulon Pers.	Asteraceae	TAM	H	A	Nk	W	Ui
Grangea maderaspatana (L.) Poir.	Asteraceae	SAM	H	A	M	RB	Ui
Hyptis suaveolens (L.) Poit.	Lamiaceae	SAM	H	A	Ch	AR	Ui
Impatiens balsamina L.	Balsaminaceae	TAM	H	A	O	RB	O
Imperata cylindrica (L.) Raeusch.	Poaceae	TAM	H	P	R	W	Ui
Indigofera astragalina DC.	Fabaceae	TAM	H	A	Ch	F	Ui
Indigofera glandulosa Wendl.	Fabaceae	TAM	H	A	M	CF	Ui
Indigofera linifolia (L.f.) Retz.	Fabaceae	SAM	H	A	M	AR	Ui
Indigofera linnaei Ali	Fabaceae	TAF	H	A	Nk	F	Ui
Indigofera trita L.f.	Fabaceae	TAF	H	P	Ch	F	Ui
Ipomoea carnea Jacq.	Convolvulaceae	TAM	S	P	M	W	Ui
Ipomoea eriocarpa R.Br.	Convolvulaceae	TAF	H	A	M	W	O
Ipomoea hederifolia L.	Convolvulaceae	TAM	H	A	Ch	F	Ui
Ipomoea obscura (L.) Ker Gawl.	Convolvulaceae	TAF	H	P	M	W	Ui
Ipomoea pes-tigridis L.	Convolvulaceae	TAF	H	A	M	W	Ui
Ipomoea quamoclit L.	Convolvulaceae	TAM	C	P	O	W	O
Lagascea mollis Cav.[#]	Asteraceae	TAM	H	A	Nk	CF	Ui
Lantana camara L.[#]	Verbenaceae	TAM	S	P	B, M	F	O
Leonotis nepetifolia (L.) R.Br.	Lamiaceae	TAF	H	A	M	W	Ui
Leucaena latisiliqua (L.) Gillis[#]	Mimosaceae	TAM	H	P	Fo	W	Fo
Ludwigia adscendens (L.) Hara	Onagraceae	TAM	H	A	Ch	A	Ui
Ludwigia octovalvis (Jacq.) Raven	Onagraceae	TAF	H	A	M	RB	Ui
Ludwigia perennis L.	Onagraceae	TAF	H	A	M	RB	Ui
Malachra capitata (L.) L.	Malvaceae	TAM	H	A/P	M	W	Ui
Malvastrum coromandelianum (L.) Garcke	Malvaceae	TAM	H	A	M	W	Ui
Martynia annua L.	Pedaliaceae	TAM	H	P	M	W	Ui
Mecardonia procumbens (Mill.) Small	Scrophulariaceae	TAM	H	A	Ch	W	Ui
Melilotus alba Medik. ex Desr.	Fabaceae	EU	H	A	Ch	CF	Fo
Melochia corchorifolia L.	Sterculiaceae	TAM	H	P	V	F	Ui
Merremia aegyptia (L.) Urban.	Convolvulaceae	TAM	C	P	M	AR	Ui
Mikania micrantha Kunth	Asteraceae	TAM	C	P	Ch	F	Ui
Mimosa pudica L.	Mimosaceae	BR	H	P	M	F	Ui
Mirabilis jalapa L.	Nyctaginaceae	PU	H	A	O	W	O
Monochoria vaginalis (Burm.f.) K.Presl	Pontederiaceae	TAM	H	A	M	RB	Ui
Nicotiana plumbaginifolia Viv.	Solanaceae	TAM	H	A	Nk	W	Ui
Ocimum americanum L.	Lamiaceae	TAM	H	A	M	W	Ui
Opuntia stricta (Haw.) Haw.	Cactaceae	TAM	H	P	Nk	W	Ui
Oxalis corniculata L.	Oxalidaceae	EU	H	P	M	CF	Ui
Parthenium hysterophorus L.[#]	Asteraceae	TAM	H	A	Nk	W	Ui
Passiflora foetida L.	Passifloraceae	SAM	H	P	O, M	W	O
Pedalium murex L.	Pedaliaceae	TAM	H	A	M, Ch	W	Ui
Pennisetum purpureum Schum.	Poaceae	TAM	H	A	Co	F	Fo
Peristrophe paniculata (Forssk.) Brummitt	Acanthaceae	TAM	H	A	M	W	Ui
Physalis minima L.	Solanaceae	TAM	H	A	M	W	Ui
Pilea microphylla (L.) Liebm.	Urticaceae	SAM	H	A	Nk	RB	Ui
Pistia stratiotes L.	Araceae	TAM	H	P	M	A	Ui
Portulaca oleracea L.	Portulacaceae	SAM	H	A	M	W	Fd

(*Contd*)

Table 1. (*Contd*)

Species	Family	OR	LF	HA	U	HT	MI
Portulaca quadrifida L.	Portulacaceae	TAM	H	A	M	W	Ui
Prosopis juliflora (Sw.) DC.#	Mimosaceae	MX	T	P	W	W	Af
Rorippa dubia (Pers.) Hara	Brassicaceae	TAM	H	A	Nk	CF	Ui
Ruellia tuberosa L.	Acanthaceae	TAM	H	A	Ch	RB	Ui
Saccharum spontaneum L.	Poaceae	ML	H	P	R	RB	Ui
Scoparia dulcis L.	Scrophulariaceae	TAM	H	A/P	M	W	Ui
Sesbania bispinosa (Jacq.) W.Wight	Fabaceae	TAM	H	A/B	R	RB	Ui
Sida acuta Burm.f.	Malvaceae	TAM	H	A	M	W	Ui
Solanum nigrum L.	Solanaceae	TAM	H	A	Ad, M	CF	Ui
Solanum seaforthianum Andrews	Solanaceae	BR	C	P	Nk	W	Ui
Solanum torvum Sw.	Solanaceae	WI	S	P	M	F	Ui
Solanum viarum Dunal	Solanaceae	TAM	H	P	Nk	F	Ui
Sonchus asper (L.) Hill	Asteraceae	MR	H	A	Nk	AR	Ui
Sonchus oleraceus L.	Asteraceae	MR	H	A	Nk	RB	Ui
Spermacoce articularis L.f.	Rubiaceae	TAM	H	A	M	F	Ui
Spilanthes radicans Jacq.	Asteraceae	SAM	H	A	M	RB	Ui
Stachytarpheta jamaicensis (L.) Vahl	Verbenaceae	TAM	C	A/P	M	F	Ui
Synedrella nodiflora (L.) Gaertn.	Asteraceae	WI	H	A	Ch	W	Ui
Torenia fournieri Linden ex Fourn.*	Scrophulariaceae	AS	H	P	Nk	W	Ui
Tribulus lanuginosus L.*	Zygophyllaceae	TAM	H	P	M	W	Ui
Tribulus terrestris L.	Zygophyllaceae	TAM	H	P	M	W	M
Tridax procumbens L.	Asteraceae	TAM	H	P	M	CF	Ui
Triumfetta rhomboidea Jacq.	Tiliaceae	TAM	H	A	M	W	Ui
Turnera ulmifolia L.	Turneraceae	TAM	H	P	Nk	W	Ui
Typha angustifolia L.	Typhaceae	TAM	H	P	Hu	RB	Ui
Ulex europaeus L.	Fabaceae	EU	S	P	Nk	W	Ui
Urena lobata L.	Malvaceae	TAM	S	A/P	M	W	Ui
Waltheria indica L.	Sterculiaceae	TAM	S	P	M	F	Ui
Xanthium indicum Koenig	Asteraceae	TAM	S	A	M, Bf	AR	Ui
Youngia japonica (L.) DC.	Asteraceae	SAM	H	A	Nk	AR	Ui

OR, Origin; SAM, South America; BR, Brazil; TAM, Tropical America; EU, Europe; TAF, Tropical Africa; AS, Australia; WI, West Indies; MG, Madagascar; MR, Mediterranean region; NAM, North America; AF, Afghanistan; CAM, Central America; PU, Peru; MX, Mexico; ML, Malaysia.
LF, Life form; H, Herb; C, Climber; S, Shrub; T, Tree; L, Liana.
HA, Habit; A, Annual; B, Biennial; P, Perennial; P/B, Perennial or biennial; A/P, Annual or perennial.
U, Uses; Ad, Adulteration; B, Basket making; Bf, Biomass fuel in rural area; Ch, Presence of bioactive chemicals; Co, Compost; Fo, Fodder; Hu, Hut thatch; Hf, Hand-held fan; M, Medicinal; Nk, Not known; O, Ornamental; R, Rope making; St, Secondary waste water treatment; V, Vegetable; W, Wood work.
HT, Habitat; W, Wastelands; CF, Cultivated fields; RB, River and pond banks; F, Forests; AR, Along roadside; A, Aquatic; P, Parasites.
MI, Mode of introduction; Af, Agroforestry; Fd, Food; Fo, Fodder; M, Medicinal; O, Ornamental; Ui, Unintentional.
#Allelopathic potential; *Species not listed in *Global Compendium of Weeds*[45].

Nativity of the plants was recorded from the published literature[34–43]. Putative modes of introduction of these species in India, where available in the literature, were recorded and categorized as food, fodder, medicinal, ornamental and unintentional. Plants were categorized by life form (herb, shrub, climber, tree, liana) and habit (annual, perennial, biennial). Habitat (wasteland, cultivated field, river and pond banks, forest, roadside, aquatic) where a given species was most abundant was also noted. Parasitic plants were also recorded. Literature and local people were consulted to find out anthropogenic use, if any, of these species.

Total 152 species distributed in 109 genera and 43 families were recorded as invasive aliens in the flora of UP. These are listed in Table 1. Only 17 species seem to have been introduced deliberately, the rest of them unintentionally through trade exchanges including grain import. Many of these species are known invasives elsewhere also. For example, eight species listed in Table 1 are included among the 37 species categorized as most noxious invasives in China[11], and 43 species are common to the alien flora of Taiwan[44]. Of these, the following seven species are common to China, Taiwan and UP: *Alternanthera philoxeroides*, *Eichhornia crassipes*, *Mikania micrantha*, *Conyza canadensis*, *Galinsoga parviflora*, *Echinochloa crusgalli* and *Ageratum conyzoides*. About 91% of the species listed in Table 1 are included in the *Global Compendium of Weeds*[45].

Contribution of different geographical regions in terms of nativity is shown in Figure 1. Tropical America accounted for 62.5%; tropical Africa and South America 10.5% each and Europe 3.3% species. The remaining 13.2% species were collectively contributed by 11 regions (Figure 1). Not surprisingly, most of the inva-

sives in the state owe their origin to tropical regions. The contribution of tropical America including South America (73%) is noteworthy. The American continents contributed majority of noxious invasive plants in China also[11,46]. Huang *et al.*[11] have discussed the possible reasons for abundance of American elements in the noxious invasive flora of China. They reviewed 306 papers on invasive plants in China and found that lots of invaders from the American continent were reported to exert strong allelopathic effects on native species. According to them, this may indicate that novel weapons are a key to high impacts, and is also an evidence that species from the American continent are less related to native plants of China and therefore may exhibit strong competitive ability.

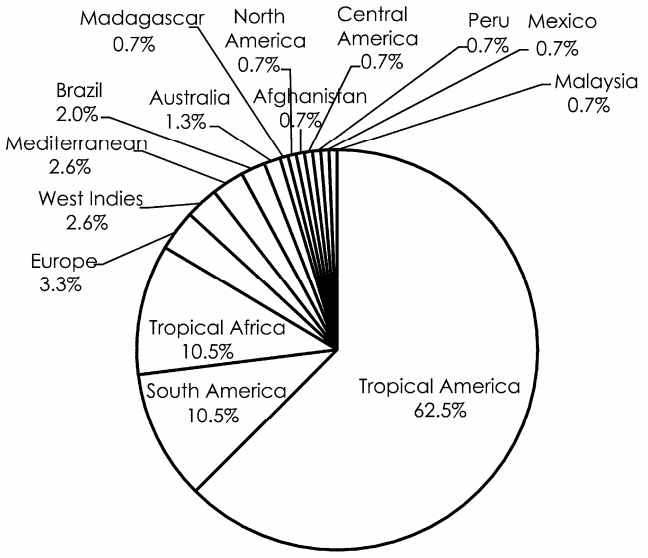

Figure 1. Contribution of different geographical regions to the invasive flora of Uttar Pradesh.

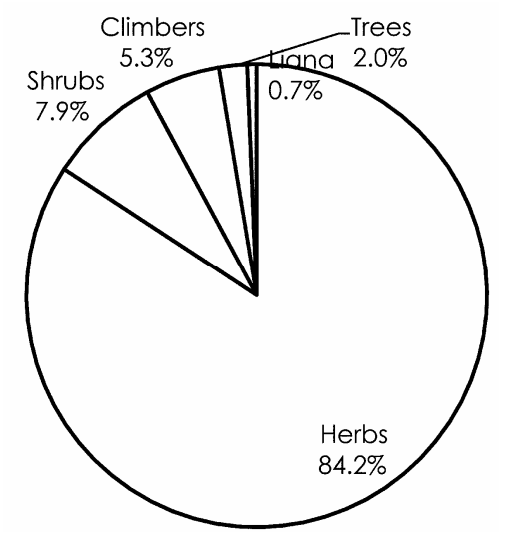

Figure 2. Habit-wise distribution of invasive species in Uttar Pradesh.

In contrast, Europian flora contributed maximum percentage of species (38) to the alien flora of Jammu and Kashmir[47]. Khuroo *et al.*[48] have argued that predominance of European elements in the alien flora of Jammu and Kashmir could be due to successful introduction owing to more or less similar climate.

Annuals comprise about 61% of the invasive alien flora of UP. Annuals are also reported to predominate the invasive flora of China, although perennial species are more noxious[11,46]. Herbs constitute 84.2% (128 species) of the invasive flora of UP, whereas trees were represented by only three species and lianas by only one species (Figure 2). Thus habit-wise classification of alien invasives shows a preponderance of herbs. Plant species with herbaceous habit dominate the alien flora of Jammu and Kashmir as the percentage of annual and perennial herbs is 32 and 27 respectively[47]. Perennial herbs are also reported to contribute substantially to the invasive flora of China[11,45]. Greater vagility and tolerance to harsh conditions[10] could result in the preponderance of herbs in the alien flora.

The genera with the highest number of alien invasive taxa in UP are *Ipomoea* and *Cassia* (six species each), and *Indigofera* and *Corchorus* (five species each). The top nine genera contributed 26.3% species (Figure 3), whereas 12 genera accounted for 16%, and 88 genera contributed one species each, accounting together for 58% of the species. In the alien flora of the state, Asteraceae is the most dominant family with 30 species, followed by Fabaceae with 12 species, Amaranthaceae, Solanaceae and Convolvulaceae with eight species each, Poaceae with seven species, Caesalpiniaceae and Tiliaceae with six species each, Capparaceae, Euphorbiaceae, Asclepiadaceae, Malvaceae and Mimosaceae with four species each. These 13 families contributed 69% of the alien invasive flora (Figure 4). Thirteen species contributed 2–3 species each, whereas 18 species contributed

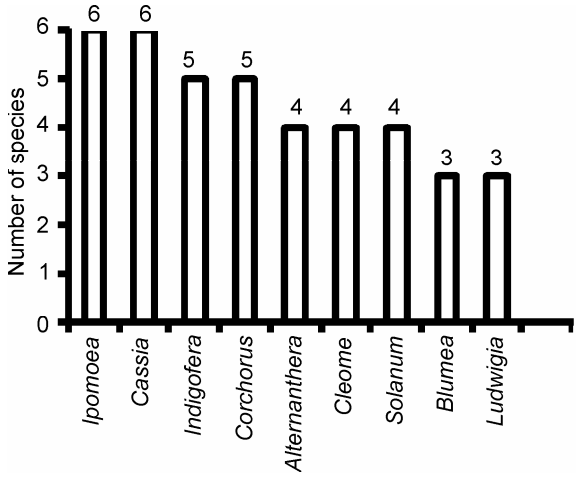

Figure 3. Genera with three or more species in the invasive flora of Uttar Pradesh.

one species each (Table 1). Rao and Murugan[48] also found Asteraceae to dominate the invasive alien flora of India. Asteraceae contributed maximum number of noxious invasive species also in China[11]. Asteraceae was the second largest, next to Poaceae, contributor to the invasive alien flora of Jammu and Kashmir[47]. Asteraceae contributed most of the exotic weed species also in South Africa[49]. Thus, all flowering families are not equally represented in the invasive flora of UP. It is possible that the larger the family, the more the species it could contribute to the invasive flora. However, further research is needed to find out the explanation for the over-representation of certain genera/families compared to others in the invasive flora of a region, e.g. N-fixing capacity of members of Fabaceae could help them in colonizing the empty niches.

About 47% of invasive species were most abundant in wastelands, while cultivated fields, banks of water bodies and forest were preferred by 17%, 14% and 12% species respectively (Figure 5). Relative degree of disturbance in these habitats, apart from other abiotic and biotic characteristics, might be responsible for this pattern. Disturbance may free resources, open up space and change the physical environment; thereby it can create opportunities for non-indigenous species to invade systems[50].

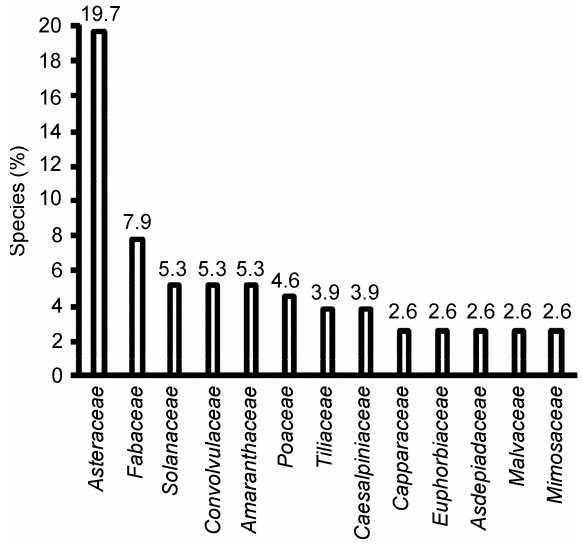

Figure 4. Families accounting for more than 2% species in the invasive flora of Uttar Pradesh.

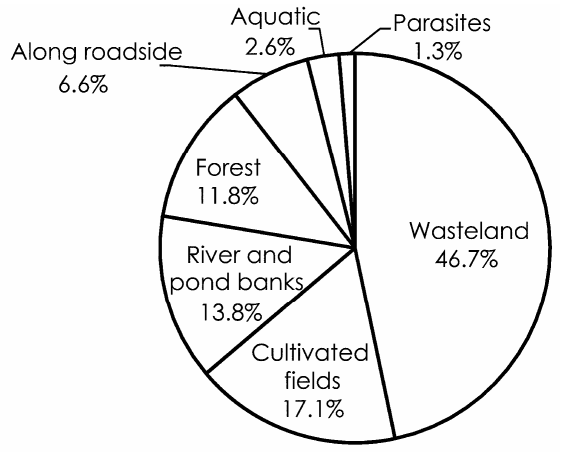

Figure 5. Habitat-wise distribution of invasive species in the flora of Uttar Pradesh.

Our field observations and discussion with local people indicated that the 10 most noxious invasive plant species in the state are *Lantana camara*, *Eichhornia crassipes*, *Parthenium hysterophorus*, *Prosopis juliflora*, *Xanthium indicum*, *Argemone mexicana*, *Ageratum conyzoides*, *Hyptis suaveolens*, *Cassia tora* and *Mikania micrantha.* However, quantitative impact of these species on the indigenous flora and invaded ecosystems is yet to be studied.

A search in the literature and consultation with local people indicated that several of the invasive species are also being used for different purposes; for example, *Lantana* is being used for basket-making and leaves of *Saccharum spontanium* for rope making and as thatching material. Twenty four species listed in Table 1 are reported to be used by tribals for medicinal purposes[51] and 60 species are listed as having medicinal value in *Wealth of India*[52]. Several of these are used for adulteration; for example mustard oil is adulterated with extract from seeds of *A. mexicana*.

The effects of invasion include colonizing species becoming pests and/or leading to disappearance of native species, and their importance needs to be measured by evaluating their impact on human population, health and biodiversity, causing losses both in terms of social impacts and to the economy. Putting a realistic monetary value will attract intensive efforts towards their control. Studies are also needed to understand their introduction pathway and status, i.e. whether they have been just recently introduced or are now firmly established, and to quantify the severity of invasion in different habitats. The state presently has one National Park and 23 Wildlife Sanctuaries (12 of avian importance popularly known as bird sanctuaries). Each protected area should develop its own database on invasives for monitoring and management.

There are four main strategies to control or eradicate invasive species: manual, mechanical, chemical and biological[53]. Often the success of biological control programmes is not clear-cut, because complete control is only achieved in some years and/or at some localities[54]. In India, the biocontrol agent (*Teleonemia scrupulosa*) released for *Lantana* control failed since the control agent could not cope with the vigorous regrowth of *Lantana* at the onset of monsoon rains, or the control agent itself suffered heavy mortality during winter months[55]. Evidently, there is need for concerted research on suitable and environment-friendly control measures. CAB International on behalf of Global Invasive Species Programme (GISP)

proposes three major management options, prevention, early detection and eradication[56]. It should also be debated whether or not intensive exploitation can be a part of management strategy? For developing suitable management strategies, it is essential to examine the ecology and genetic make-up of the concerned invasive species. The pathways or mechanisms that underlie the impacts of exotic plant invasions on community structure and ecosystem processes and why exotic plants impact only certain systems, and why only some invaders have large impacts are poorly understood[57]. Lee[58] emphasizes the utility of genomic approaches for determining invasion mechanisms, through analysis of gene expression, gene interactions and genomic rearrangements that are associated with invasion events.

1. Mack, R. N. *et al.*, Biotic invasions: causes, epidemiology, global consequences and control. *Ecol. Appl*., 2000, **10**, 689–710.
2. Williamson, M., *Biological Invasion*, Chapman and Hall, London, 1996.
3. Levine, S. A., Analysis of risk for invasions and control program. In *Biological Invasion*: *A Global Perspective, SCOPE* 37 (eds Drake, J. A. *et al.*), John Wiley, Chichester, UK, 1989, pp. 425–435.
4. McNeely, J. A., An introduction to human dimensions of invasive alien species. Human dimension of the consequences of invasive alien species, ISSG, IUCN, 2001; www.issg.org
5. Perrings, C. *et al.*, Biological invasion risks and public good: an economic perspective. *Conserv. Ecol*., 2002, **6**, 1.
6. Schei, P. J., Conclusion and recommendation from the UN/ Norway, Conference on Alien species. *Sci. Int*., 1996, **63**, 32.
7. Vitousek, P. M. *et al*., Introduced species: a significant component of human-caused global change. *New Zealand J. Ecol*., 1997, **21**, 1–16.
8. Rejmanek, M. and Randall, J. M., Invasive alien plants in California: 1993 summary and comparison with other areas in North America. *Madroño*, 1994, **41**, 161–177.
9. Simberloff, D., Parker, I. M. and Windle, P. M., Introduced species policy, management and future research needs. *Front. Ecol. Environ*., 2005, **3**, 12–20.
10. Sharma, G. P., Singh, J. S. and Raghubanshi, A. S., Plant invasions: emerging trends and future implications. *Curr. Sci*., 2005, **88**, 726–734.
11. Huang, Q. Q., Wu, J. M., Bai, Y. Y., Zhou, L. and Wang, G. X., Identifying the most noxious invasive plants in China: role of geographical origin, life form and means of introduction. *Biodivers. Conserv*., 2009, **18**, 305–316.
12. Higgins, S. I. and Richardson, D. M., A review of models of alien plant spread. *Ecol. Model.*, 1996, **87**, 249–265.
13. Singh, J. S., Singh, S. P. and Gupta, S. R., *Ecology Environment and Resource Conservation*, Anamaya Publishers, New Delhi, 2006.
14. Nayar, M. P., Changing patterns of the Indian flora. *Bull. Bot. Surv. India*, 1997, **19**, 145–154.
15. Khanna, K. K., Mudgal, V., Uniyal, B. P. and Sharma, J. R., *Dicotyledonous Plants of Uttar Pradesh – A Checklist*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 1999.
16. Duthie, J. F., *Flora of the Upper Gangetic Plains and of the Adjacent Siwalik and Sub-Himalayan Tracts*, Culcutta, 1903–1929.
17. Kanjilal, P. C., *A Forest Flora of Pilibhit, Oudh, Gorakhpur and Bundelkhan* (repr. ed.), Narendra Publication House, Delhi, 1982.
18. Singh, N. P., Flora of Bulandshahr district. *Bull. Bot. Surv. India*, 1969, **11**, 1–22.
19. Srivastava, T. N., *Flora of Gorakhpurensis*, Today and Tomorrow's Print and Publication, New Delhi, 1976.
20. Uniyal, B. P., Balodi, B. and Baij Nath, *Grasses of Uttar Pradesh – A Checklist*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 1994.
21. Uniyal, S. K., Swami, A. and Uniyal, B. P., *Cyperaceae of Uttar Pradesh – A Checklist*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 1997.
22. Uniyal, S. K., Swami, A. and Uniyal, B. P., *Monocotyledonous Plants of Uttar Pradesh* – (*Excluding Cyperaceae and Poaceae*) *A Checklist*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 1999.
23. Narayan, S., Flora of Hamirpur District, UP, Ph D thesis, University of Allahabad, Allahabad.
24. Shukla, G., Flora of Jalaun District, UP, Ph D thesis, University of Allahabad, Allahabad.
25. Sinha, B. K., Flora of Banda District, UP, Ph D thesis, University of Allahabad, Allahabad.
26. Shukla, B. K. and Sinha, B. K., Grasses of Bundelkhand (Uttar Pradesh) – taxonomic studies. *J. Non-Timber Forest Products*, 2004, **11**, 274–315.
27. Sharma, B. D. and Pandey, D. S., *Exotic Flora of Allahabad District*, Botanical Survey of India, Howrah, 1984.
28. Sharma, S. C., Malik, S. A. and Sharma, A., The exotic plants in the vegetation of Shahjahnpur district (UP). *J. Econ. Tax. Bot*., 2007, **31**, 235–243.
29. Singh, K. K. and Bhatt, H. S., Exotic flora of Kheri District, Uttar Pradesh. *Bot. Progr*., 1979, **2**, 70–73.
30. Singh, S. C. and Srivastava, G. N., Exotic medicinal plants of Lucknow district, UP, India. *J. Econ. Tax. Bot*., 1999, **23**, 223–235.
31. Raizada, M. P., Recently introduction or otherwise imperfectly known plants from the Upper Gangetic Plains. *J. Indian Bot. Soc*., 1935, **14**, 339–348.
32. Srivastava, A. K., Exotic weeds of Gorakhpur district, UP. *J. Econ. Tax. Bot*., 1993, **17**, 261–263.
33. Rajagopal, T. and Panigrahi, G., 'Aliens' naturalized in the flora of Allahabad. *Proc. Nat. Acad. Sci. India B*, 1965, **35**, 411–422.
34. Chatterji, D., Influence of east Mediterranean regions flora on that of India. *Sci. Cult*., 1947, **13**, 9–11.
35. Maheshwari, J. K., Studies on the naturalized flora of India. Proceedings of the Summer School of Botany, New Delhi, 1960, pp. 156–170.
36. Reddy, C. S., Bagyanarayana, G., Reddy, K. N. and Raju, V. S., *Invasive Alien Flora of India*, National Biological Information Infrastructure, USGS, USA, 2008.
37. Matthew, K. M., Alien flora of Kodai Kanal and Palni hills. *Rec. Bot. Surv. India*, 1969, **20**, 1–241.
38. Maheswari, J. K. and Paul, S. R., The alien flora of Ranchi. *J. Bombay Nat. Hist. Soc*., 1975, **72**, 158–188.
39. Hajra, P. K. and Das, B. K., Vegetation of Gangtok with special reference to alien plants. *Indian For*., 1982, **107**, 554–566.
40. Pandey, R. P. and Parmar, The alien flora of Rajasthan. *J. Econ. Tax. Bot*., 1994, **18**, 105–121.
41. Negi, P. S. and Hajra, P. K., Alien flora Doon Valley, North West Himalaya. *Curr. Sci*., 2007, **92**, 968–978.
42. Srivastava, J. D., Some tropical American and African weeds that have invaded the state of Bihar. *J. Indian Bot. Soc*., 1964, **43**, 102–112.
43. Pandey, D. S., Exotics-introduced and natural immigrants, weeds, cultivated, etc. In *Flora of India: Introductory Volume, Part II* (eds Singh, N. P. *et al.*), Botanical Survey of India, Calcutta, 2000, pp. 266–301.
44. Wu, S.-H., Hsieh, C.-F. and Rejmánek, M., Catalogue of the naturalized flora of Taiwan. *Taiwania*, 2004, **49**, 16–31.
45. Randall, R. P., *A Global Compendium of Weeds*, R. G. and F. J. Richardson, Melbourne, 2002.

46. Xu, H. G. and Qiang, S., *Inventory of Invasive Alien Species in China*, China Environmental Science Publication, Beijing, 2004.
47. Khuroo, A. A., Rashid, I., Reshi, Z., Dar, G. H. and Wafai, B. A., The alien flora of Kashmir Himalaya. *Biol. Invas.*, 2007, **9**, 269–292.
48. Rao, R. R. and Murugan, R., Impact of exotic adventives weeds on native biodiversity in India: implications for conservation. In *Invasive Alien Species and Biodiversity in India* (eds Rai, L. C. and Gaur, J. P.), Banaras Hindu University, 2006, pp. 93–109.
49. Heywood, V. H., Patterns, extents and modes of invasions. In *Biological Invasion: A Global Perspective* (eds Drake, J. A. *et al*.), John Wiley, New York, 1989, pp. 31–60.
50. Hobbs, R. J. and Huenneke, L. F., Disturbance, diversity, and invasion – implications for conservations. *Conserv. Biol.*, 1992, **6**, 324–337.
51. Singh, A. K., Raghubanshi, A. S. and Singh, J. S., Medical ethnobotany of the tribals of Sonaghati of Sonbhadra district, Uttar Pradesh, India. *J. Ethnopharmacol.*, 2002, **81**, 31–41.
52. Anon., *Wealth of India-Raw Materials*, Council of Scientific and Industrial Research, New Delhi, 1948–1992, vols I–X.
53. Hobbs, R. J. and Humphries, S. E., An integrated approach to the ecology and management of plant invasions. *Conserv. Biol.*, 1995, **9**, 761–770.
54. Syrett, P., Briese, D. T. and Hoffmann, J. H., Measures of success in biological control of terrestrial weeds by anthropods. In *Measures of Success in Biological Control* (eds Wratten, S. D. and Gurr, G.), Kluwer, Amsterdam, 2000, pp. 189–230.
55. Sharma, O. P., How to combat *Lantana* (*Lantana camara* L.) menace? A current perspective. *J. Sci. Ind. Res.*, 1988, **47**, 611–616.
56. Wittenberg, R. and Cock, M. J. W. (eds), *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*, CABI Publication, UK, 2001, p. 228.
57. Levine, J. M., Vila, M., D'Antonio, C. M., Dukes, J. S., Grigulis, K. and Lavorel, S., Mechanisms underlying the impacts of exotic plant invasions. *Proc. R. Soc. London B*, 2003, **270**, 775–781.
58. Lee, C. E., Evolutionary genetics of invasive species. *Trends Ecol. Evol.*, 2002, **17**, 386–391.

ACKNOWLEDGEMENTS. K.P.S. and A.N.S. thank Director, Botanical Survey of India, Kolkata for the encouragement and facilities. J.S.S. is supported by NASI Platinum Jubilee Fellowship.

Received 6 July 2009; revised accepted 4 June 2010

A new phonic type of the rufous horseshoe bat *Rhinolophus rouxii* from southern India

Balaji Chattopadhyay[1], Gerd Schuller[2], Kritika M. Garg[3] and Sripathi Kandula[1,*]

[1]School of Biological Sciences, Madurai Kamaraj University, Madurai 625 021, India
[2]Biozentrum der Universität, München, Department Biologie II, Grosshaderner Str. 2, D-82152 Planegg_Martinsried, Germany
[3]National Centre for Biological Sciences, GKVK Campus, Bangalore 560 065, India

The Old World horseshoe bats are speculated to comprise of enormous cryptic diversity. The only Rhinolophid that has been studied with some detail in the subcontinent is the rufous horseshoe bat *Rhinolophus rouxii*. This bat has shown some extent of acoustic diversity between allopatric population of Peninsular India and Sri Lanka. As part of a long-term study of cryptic diversity we discovered a new phonic type of this bat in Southern India. Bats sampled from Yercaud, Tamil Nadu have principal frequencies above 90 kHz, whereas previously reported principal frequencies from bats of allopatric populations of Mahabaleswar and Srirangapattana are below 85 kHz. Interestingly, the difference between the principal frequencies of the Srirangapattana and Yercaud populations are more than those between Mahabaleswar and Srirangapattana populations, indicating the possible presence of cryptic lineages with in this species in Southern India.

Keywords: Cryptic species, echolocation, principal frequency, *Rhinolophus rouxii*.

OVER the past decades, echolocation calls have been used successfully to identify cryptic species in the order Chiroptera. Study of acoustic divergence of morphologically indistinguishable individuals from sympatric and allopatric populations has established the fact that such individuals can belong to different phonic types. Often molecular genetic analysis of such phonic types has confirmed that individuals belonging to different phonic types are genetically diverse enough to demand separate species rank[1–3]. Morphologically cryptic but acoustically divergent bat species are now more of a norm rather than an exception. Identification of cryptic diversity is an essential component of conservation management as it ensures a more detailed assessment of the presence and status of existing biodiversity[4].

As reports of cryptic bat species are primarily from the temperate zone[2] and relatively rare in the Old World tropics, there has been a recent impetus in such study[2,3]. Acoustic divergence in tropical bat fauna is assumed to

*For correspondence. (e-mail: sribat@gmail.com)