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Invasion by *Austroeupatorium inulifolium* (Asteraceae) arrests succession following tea cultivation in the highlands of Sri Lanka

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ABSTRACT

An understanding of floral succession is vital in planning the restoration of native vegetation in abandoned agricultural landscapes. Although such restoration is essential for the establishment of habitat corridors between the fragments of tropical montane cloud forest in the Sri Lankan highlands, in which > 90% of the land has been converted to tea plantations, no studies of succession have hitherto been possible because of the near-total absence of secondary forest in this region. In a pioneering restoration initiative in 1998, however, tea cultivation was abandoned on a 25 ha site (elevation 1540–1780 m) at Agrapatana, ~500 m from a natural forest. Succession was allowed to proceed without intervention, except that tea was removed from 10 ha. By 2009, the invasive Neotropical shrub *Austroeupatorium inulifolium* and Australian tree *Acacia decurrens* dominated the vegetation (0.43±0.14 and 0.03±0.04 stems m^{-2}, respectively), to the total exclusion of native woody species. There was no significant difference in the density of *Austroeupatorium* (82±12%) and *Acacia* (14±9%) between quadrats with and without tea. Methods to suppress these two aggressive invasive species are urgently needed, especially given that *Austroeupatorium* has recently become established within pristine montane forests such as Horton Plains National Park (2,100 m elevation).

Key words: *Acacia decurrens*, *Eupatorium*, montane cloud forest, invasive species

INTRODUCTION

Sri Lanka (65,000 km^2) is part of a Global Biodiversity Hotspot (Mittermeier *et al.*, 2004). Some 977 vascular-plant species and 278 vertebrate species are endemic to it (Green *et al.*, 2009). Much of this diversity is concentrated in the tropical montane cloud forests (TMCFs) of the island's central hills, which rise to 2,524 m. With extensive deforestation for planting of tea (*Camellia sinensis*, F.Theaceae) during the 19th century, the area of TMCF has declined to about 300 km^2, approximately 10% of its pre-colonial extent (Werner, 1995, 2001). TMCF now persists in the form of 18 discrete fragments within a landscape dominated by tea (Forestry Planning Unit 1995). The establishment of habitat connectivity between these forest fragments, through the restoration of native forest vegetation, is considered a high priority for the conservation of Sri Lanka's montane biodiversity (Wikramanayake and Gunatilleke, 2002).

The first step in the establishment of such corridors must be the abandonment of tea cultivation between existing montane-forest fragments. The high economic value of this land (~\$15,000 ha^{-1}), however, has hitherto precluded substantial tracts from becoming available for conversion to secondary forest, and consequently the extent of montane secondary forest in the Sri Lankan highlands remains negligible (Perera, 2001).

An exception has been The Totum at Agrapathana, a 25 ha tea plantation at 1540–1780 m above sea level established ca 1890 on which, in a pioneering restoration initiative, tea cultivation was aban-doned in 1998. Tea trees were uprooted from an area totaling 10 ha but retained in a further 10 ha, and succession allowed to proceed without further intervention.

Natural-forest succession following acute degradation at such sites at similar elevations elsewhere in the tropics (Sarmiento, 1997; Slocum *et al., 20*04) or at lower elevations in Sri Lanka (Cohen *et al*., 2006; Gunaratne *et al*., 2010) is sometimes arrested by a dense growth of grasses and/or ferns. At The Totum, however, by 2009 succession by native woody pioneers had been entirely thwarted by the aggressive alien species *Austroeupatorium inulifolium* (Asteraceae, a Neotropical shrub) and—to a lesser extent—*Acacia decurrens* (Fabaceae, an Australian tree) (Fig. 1).

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Figure 1. Secondary vegetation at the study site at Agrapatana, Sri Lanka, comprising of a dense growth of the exotic shrub *Austroeupatorium inulifolium* interspersed with the wattle tree *Acacia decurrens*; the tree fern *Cyathea crinita* (left) and tea, *Camellia sinensis* (bottom right).

While both these species had previously been recorded as naturalized in Sri Lanka (Dassanayake and Fosberg, 1980–2006), neither has hitherto been reported to be invasive. Here, in addition to describing a successional vegetation dominated by *Austroeupatorium* and *Acacia* at the study site 11 years after the abandonment of tea cultivation, we show that the retention or removal of tea does not result in significantly different successional outcomes. We also draw attention to the rapid invasion by *Austroeupatorium* of extensive tracts of hitherto undisturbed montane forests in Sri Lanka.

MATERIAL AND METHODS

Study area

The Totum is a 25 ha property (06°50'N, 80° 40'E) located on a NE-facing hillside. Rainfall (~2,000 mm y^{-1}) in the area, which is frequently enveloped in mist, is a seasonally distributed (~220 rainy days per year), except for a dry season in February–March. By 1998, heavy erosion resulting from a century of poor sloping-land management (Hewawasam *et al.*, 2003) had resulted in almost all topsoil being lost and the ultisolic subsoil being exposed.

The Agrabopath TMCF lies southeast and southwest of The Totum, separated from it by a strip of tea about 300 m wide. The following tree species are predominant in its canopy and subcanopy: *Calophyllum walkeri* (Clusiaceae), *Syzygium revolutum* (Myrtaceae), *Symplocos cochin-sinensis* (Symplocaceae), *Neolitsea fuscata, Cinnamomum ovalifolium* and *Actinodaphne speciosa* (Lauraceae). *Strobilanthes* (Acanthaceae) shrubs are ubiquitous in the understorey, among which are interspersed dense stands of the bamboo, *Arundinaria debilis*. An unpublished inventory of the flora of Agrabopath in 2000 by C.N. Karunatilake and A.J. Wijeratne, voucher specimens of which are preserved in The Totum's herbarium, lists 51 species of trees and shrubs with 21 endemics and in addition 44 herbaceous plants with 11 endemics (Table 1). By comparison, Balasubramaniam *et al.* (1993) found that 50% of woody species sampled in the TMCF of Horton Plains (2100 mm asl), about 15 km from Agrabopath, were endemic.

Sampling

In July–August 2009 the vegetation in the study site was censused in 32 (10×10 m) quadrats approximately 100 m inside of the site's boundary and equidistant from Agrabopath, the nearest native-plant seed source. Sixteen quadrats were in the area in which tea was removed in 1998, and the other sixteen in areas in which tea was retained, but unharvested. No intervention took place in or near each 'treatment'. All woody plants and tree ferns (considered 'trees' in the analysis) > 1 m tall were counted and identified against the herbarium, verified using the literature (Dassanayake and Fosberg, 1980–2006); herbaceous plants > 1 m were inventoried but not counted.

Statistical analysis

Only woody species and tree ferns were included in the analyses (Table 2). Species diversity (Simpson's Diversity Index, D) and relative density of *Austroeupatorium* and *Acacia* were calculated for each quadrat. Data were arcsine transformed to fulfill assumptions of normality. To compare the successional vegetation in the two treatments, analyses of variance were performed to test for differences in species diversity, and the relative density of *Austroeupatorium* and *Acacia* in quadrats with and without tea.

Table 1. Trees, tree-shrubs and shrubs recorded from Agrabopath Tropical Montane Cloud Forest reserve, Sri Lanka. *Endemic species.

Family	Species
Acanthaceae	*Strobilanthes nockii**
	Strobilanthes sexennis
Apocynaceae	*Rauvolfia densiflora*
Aquifoliaceae	*Ilex walkeri*
Asteraceae	*Anaphalis pelliculata**
	*Vernonia setigera**
	*Vernonia wightiana**
Celastraciacae	*Euonymus revolutus**
	*Microtropis zeylanica**
Clusiaceae	*Calophyllum walkeri**
	Garcinia echinocarpa
Cyathiaceae	*Cyathea crinita**
	*Cyathea walkerae**
Dilleniaceae	*Schumacheria alnifolia**
Ericaceae	*Vaccinium leschenaulti*
Euphorbiaceae	*Homalanthus populifolius*
	Macaranga peltata
Flacourtiaceae	*Casearia thwaitesii*
Lauraceae	*Actinodaphne speciosa**
	Actinodaphne molochina
	Cinnamomum ovalifolium
	Neolitsea fuscata
Liliaceae	*Asparagus gonoclados*
Melastomataceae	*Memecylon parvifolium**
Myrsinaceae	*Ardisia gardneri**
	*Ardisia wightiana**
	Maesa indica
Myrtaceae	*Rhodomyrtus tomentosa*
	Syzygium revolutum
Oxalidaceae	*Biophytum proliferum*
Rosaceae	*Rubus ellipticus*
	*Rubus leucocarpus**
	Rubus rugosus
	Prunus ceylanica
Rubiaceae	*Lasianthus gardneri*
	Psychotria sarmentosa
	*Psychotria nigra**
Rutaceae	*Acronychia pedunculata*
	Euodia lunu-ankenda
Sabiaceae	*Meliosma pinnata*
Sapotaceae	*Isonandra compta**
	*Palaquium rubiginosum**
Smilacaceae	*Smilax zeylanica*
Staphyleacae	*Turpinia malabarica*
Symplocaceae	*Symplocos bractialis**
	Symplocos cochinchinensis
	*Symplocos elegans var. minor**
	Symplocos obtusa
Theaceae	*Eurya chinensis*
	*Gordonia ceylanica**
Urticaceae	*Pilea angulata*

Table 2. Identity, status, habit and mean density (± s.d.) of plant stems > 1 m high (in 10×10 m quadrats) **(a)** with tea removed and **(b)** with tea retained in the Totum.. *Endemic species

Species	Status	Habit	Mean density (stems m^{-2} ×100)	
Woody			**(a)**	**(b)**
Austroeupatorium inulifolium	exotic	Shrub	42.5 ± 18.1	42.7 ± 8.69
Camellia sinensis	exotic	Tree	0.00 ± 0.00	8.06 ± 4.39
Acacia decurrens	exotic	Tree	3.38 ± 4.29	3.25 ± 4.18
*Cyathea crinita**	native	tree'	0.18 ± 0.54	0.69 ± 1.25
*Cyathea walkeri**	native	tree'	0.31 ± 0.60	0.50 ± 0.97
Syzygium jambos	exotic	Tree	0.75 ± 1.48	0.69 ± 1.25
*Strobilanthes nockii**	native	Shrub	0.13 ± 0.50	0.44 ± 0.96
Rubus ellipticus	native	Shrub	0.38 ± 0.62	0.50 ± 0.89
Herbaceous				
Cymbopogon nadus	exotic	Grass	9.38 ± 11.5	6.19 ± 8.82
Smilax perfoliata	native	Climber	0.27 ± 0.46	0.31 ± 0.70
Dicranopteris linearis	native	Fern	0.13 ± 0.50	0.44 ± 1.50
*Osbekia rubicunda**	native	Herb	0.25 ± 1.00	0.19 ± 0.50
Tripsacum laxum	exotic	Grass	2.13 ± 3.81	5.06 ± 8.83
Pteridium aquilinum	native	Fern	0.44 ± 1.50	0.31 ± 1.00
Tephrosia vogelii	exotic	Herb	0.00 ± 0.00	0.38±0.86

Additionally, to test for any effect *Acacia* or tea may have on *Austroeupatorium* independent of each other; four correlation coefficients (Pearson's) were calculated for correlations between the absolute densities of *Austroeupatorium* and *Acacia*, in the presence and absence of tea, using data from quadrats containing *Acacia* but not tea, (n= 7) and those containing both tea and *Acacia* (n= 9); and *Austroeupatorium* and tea, using data from quadrats containing tea but not *Acacia* (n= 8), and those containing both tea and *Acacia* (n= 8).

RESULTS

A total of 2,078 plants representing 15 species were counted, of which 1,662 (eight species) were woody (i.e. trees or shrubs; Table 2). *Austroeupatorium* accounted for 82±12% of all woody stems, and *Acacia* (14±9%). There was no significant difference in density of *Austroeupatorium* (P= 0.60, n= 32) or *Acacia* (P= 0.737, n= 32) between quadrats in which tea had been retained or removed, and no significant difference in diversity (P= 0.38 , n= 32) between these treatments (Fig. 2). There was, however, a negative correlation (r=-0.645, n=7) between the absolute density of *Austroeupatorium* and *Acacia* in quadrats lacking tea; no other correlations were found (r< 0.2, n=8).

Austroeupatorium was the dominant species in all treatments, accounting for 76±10% of woody stems in quadrats containing tea (tea represented 15±8%) and 87±12% in those from which tea had been removed; *Acacia* accounted for 11±6% and 18±11%, respectively. Only two species of native shrubs (*Rubus ellipticus* and *Strobilanthes nockii*, together representing 1.6± 2.4% of woody stems were counted), and no native tree species, were recorded (Table 1).

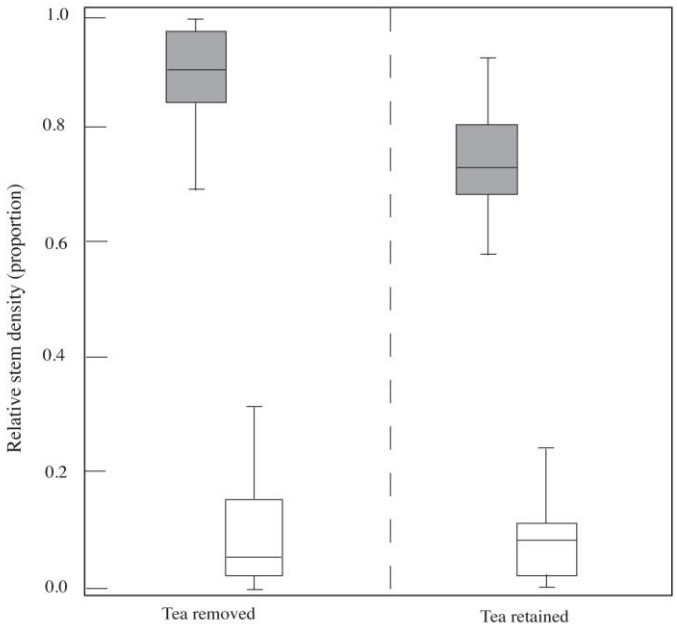

Figure 2. Relative mean density and interquartile ranges of *Austroeupatorium* (shaded bars) and all native woody plant species (clear bars) with **(a)** tea removed and **(b)** tea retained in the Totum. (Error bars indicate interquartile ranges)

DISCUSSION

Photographs taken between 1998–2000 suggest that *A. inulifolium* became established at the study site within six months of abandonment, with 2–3 m tall *Acacia* appearing by 2000. This community appears successfully to have arrested succession by native trees. Although the Agrabopath TMCF, a potential propagule source, is only 300 m distant from the boundary of The Totum; and despite the abundance at the site of perches and frugivores (e.g., the Yellow-eared bulbul *Pycnonotus penicillatus*, and the Toque macaque *Macaca sinica*), successful seed dispersal from the forest appears to have been negligible. The only native 'trees' present on the site are the tree ferns *Cyathea crinita* and *C. walkeri* (Cyatheaceae), which together account for only 2% of woody stems. The near-total absence of native secondary forest in the highlands (Perera, 2001) makes it impossible to know what the pioneer species may have been before the introduction of numerous exotics during the colonial period.

First recorded from Sri Lanka only in 1980, *A. inulifolium* has hitherto been considered rare (Grierson, 1980). Though recently recognized as naturalized in Taiwan (Hsu, 2006), the species has previously not been considered invasive in Sri Lanka or South Asia (Gunasekera, 2009). *Austroeupatorium*, however, is now becoming increasingly common on roadsides and TMCF margins at elevations >1,500 m in Sri Lanka. It is of concern that by mid-2009 substantial expanses of it had become established within 'pristine' TMCFs such as Horton Plains National Park (elevation ~2,100 m) (Fig. 3), where an intensive survey as recently as 2007 had failed to record it (Department of Wildlife Conservation, 2007).

In acutely degraded tropical montane environments in the Dominican Republic and Ecuador, succession is arrested by herbaceous vegetation comprising grasses and ferns (Perera, 2001; Slocum *et al*. 2004). In the Sri Lankan lowlands, succession has been found to be arrested by the fern *Dicranopteris linearis* (Gleicheniaceae) and the grass *Imperata cylindrica* (Cohen *et al.*, 2006). When these were removed, woody-plant recruitment included eight indigenous tree and shrub species (Cohen *et al.*, 2006). At The Totum, however, the removal of tea made almost no difference to the successional outcome. At a 1,000-m elevation site in Sri Lanka, however, even after ~30 y of abandonment of tea, succession was arrested by *Cymbopogon nardus* grass, with woody-plant seedling emergence <0.1 $m^{-2}y^{-1}$, less than a sixtieth of that in neighboring natural forest (Gunaratne *et al.*, 2010). While *C. nardus* is present at low densities in The Totum, it is clearly outcompeted by *Austroeupatorium*.

Figure 3. An expanse of *Austroeupatorium inulifolium* in Horton Plains National Park (2,100m a.s.l.), a pristine tropical montane cloud forest in central Sri Lanka, apparently replacing bracken (*Pteridium aquilinum*, darker brown area mid-right) that had previously arrested succession following a fire in 1989.

The restoration of native secondary forest in the Sri Lankan highlands is unlikely to be successful unless means of suppressing *Austroeupatorium* and *Acacia* are developed. While the latter could possibly be controlled by harvesting for timber or firewood, the former, like its relative *Chromolaena odorata* at lower elevations, is likely to pose a serious threat to the native montane flora (Sharma *et al.*, 2005) while proving difficult and expensive to eradicate at the landscape level (Honu & Dang, 2000).

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